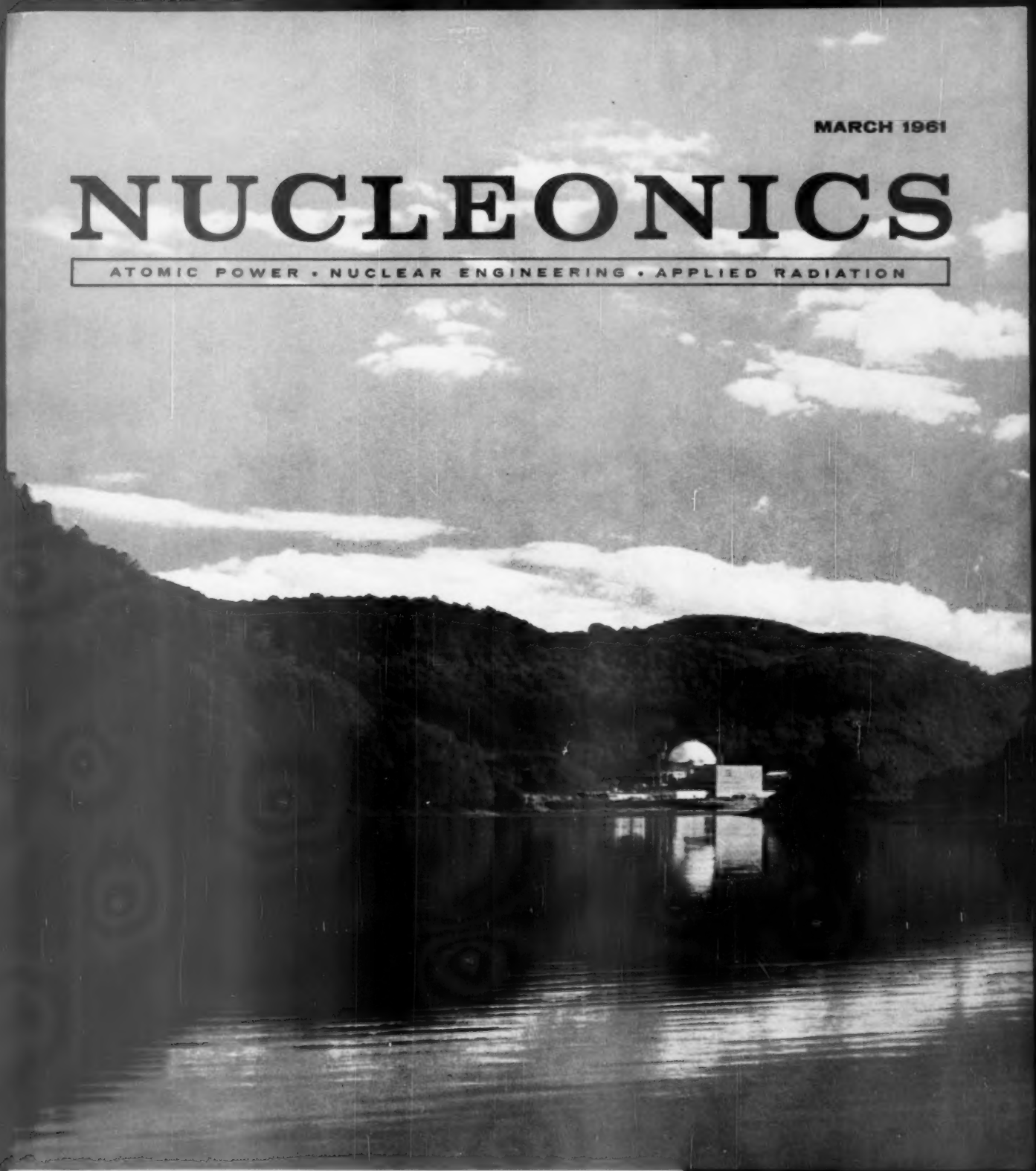
MARCH 1961

NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



YANKEE

From the Berkshire Hills,
Nuclear Electricity for New England

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AEC's Frank Pittman Reports on the SL-1 Accident . . . page 62

Magnetic Tape Speeds Nuclear Experiments . . . page 70

HAMNER

A-8 DESIGN
ULTRA HIGH SPEED, NON-OVERLOAD
LINEAR AMPLIFIERS

Unexcelled A-8 Characteristics . . . PLUS

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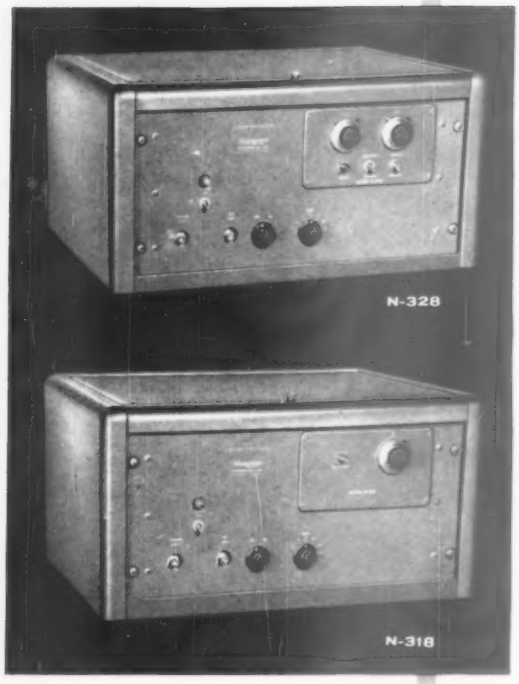
- OPTIONAL PICK-OFF FOR 40 mμs RANGE COINCIDENCE
- YOUR CHOICE OF DISCRIMINATORS



The A-8 Design Amplifier has found wide usage in nuclear physics laboratories where one or more of the following three conditions exist:

1. Very large overload signals will be present.
2. Counting rates up to 250kc will be present.
3. It is required to do medium-fast coincidence work on pulses having slow risetimes.

In these three areas, the A-8 design represents a great improvement over previous units.

These results are achieved through the use of double differentiation with two delay lines, thus providing for fast baseline recovery even under high-duty cycle operation. Overload performance is enhanced by preventing the Amplifier from overloading before differentiation and by not allowing overload to occur inside a feedback loop.

N-308
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Maximum Gain: 7000 in main Amplifier (additional gain of 1, 3 or 10 in Pre-Amp).

Gain Stability: 0.25% day.

Risetime: About 0.2 μs.

Linearity: 0.1% Integral Linearity, 3-100 volts into 10K or greater load.

Overload Recovery: About 8 μs for 4000 times overload.

Maximum Counting Rate: About 250,000 CPS.

N-318
AMPLIFIER WITH INTEGRAL DISCRIMINATOR

Amplifier Section: See details on N-308.

Discriminator Section: This Discriminator is based on the P. R. Bell Design.

Range: 4-100 volts by 10-turn helipot.

Linearity: Better than 0.5%, 3-100 volts.

Stability: Better than 50 mv/day.

Resolving Time: About 1.2 μs.

Output Pulse: 1 μs wide, +50 volts high into 10K load.

N-328
AMPLIFIER WITH PULSE-HEIGHT ANALYZER

Amplifier Section: See details on N-308.

Output Pulse Height: (25 volts, positive or negative by switch.)

Baseline:
Control—By 10-turn helipot.
Range—3-100 volts by 10-turn helipot.
Linearity—0.1%, 3-100 volts.
Stability—Better than 50 mv/day.

Window:
Control—By 10-turn helipot.
Width—0-10 volts by 10-turn helipot (0-20, 30, 40 or 50 volts at slight extra cost).

N-670 COINCIDENCE PICKOFF. In Coincidence Work, the time of the pulse zero crossover is largely independent of pulse-height. For this reason, it is well related in time to the event causing the pulse and is useful for coincidence studies. Coincidence resolving times of less than 50 mμs can be successfully used with Sodium Iodide. The N-670 is an optional sub-chassis which detects the zero crossing and presents an output for coincidence work.

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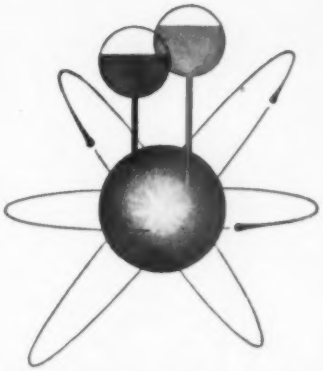
Department 3

Now–Cut Nuclear Power Costs with the Spectral Shift Control Reactor

The Babcock & Wilcox Company presents a high capacity reactor which incorporates significant improvements in neutron economy, power distribution within the core, and core lifetime. The Spectral Shift Control Reactor (SSCR) is the outgrowth of extensive research and engineering on the time-proven pressurized water concept. It operates with a mixture of heavy and light water which shifts the neutron spectrum so as to control resonance absorption in the fertile material during the life of the core. As the reactor is operated, the addition of light water makes neutrons available to sustain criticality for substantially increasing core lifetime.

NEUTRON ECONOMY

The excess mass of fuel required for long core lifetime is controlled by heavy water instead of neutron-absorbing materials, such as control rods or soluble poisons. In fact, at full power the SSCR operates with most of its control rods completely withdrawn. Neutrons which in other reactors would be wastefully absorbed in control rods, or soluble poisons, are instead absorbed in the fertile material to produce new fuel. Conversion ratio is improved for both thorium and low enrichment uranium cycles, resulting in extended core life. A breeding ratio greater than unity may ultimately be achieved with recycled U-233 fuel. The inherent neutron savings alone in the SSCR make it an important



step toward the achievement of economic power.

POWER FLATTENING

In other water reactors, control rods in the core distort the power distribution. The reduced number of rods in the SSCR core provides the highest degree of power flattening available in any reactor today over the entire core life. For this reason, the SSCR core can produce substantially more power than other reactor cores of comparable size. Substantial savings in unit capital costs of the reactor primary loop, shielding, and containment are thus achieved.

LONGER CORE LIFE

The ability of D_2O to hold down excess reactivity permits a high initial fuel loading which allows core lifetime to be extended far beyond the margins presently imposed by material limitations. Since irradiation damage to oxide fuels appears to be inconsequential, lifetimes of future cores may be limited only by neutron absorption in the fission products themselves.

FLEXIBILITY

The SSCR can control various amounts of excess reactivity permitting ready adaptation to future cores that have the optimum combination of fuel type enrichment and cladding. Benefits from the thorium-uranium 233 fuel cycle, when it is developed, can be immediately attained.

Recently, the Atomic Energy Commission awarded to B&W a million dollar contract for critical and exponential experiments on the mixed water moderator principle. The information obtained will be valuable in furthering the development and application of all reactor designs utilizing mixed moderators, including the SSCR. The combination of the Spectral Shift Control concept with the advanced technology of the pressurized water reactor yields one of the most advanced nuclear power reactors that can be offered to the utility industry today. The Babcock & Wilcox Company, 161 East 42nd Street, New York 17, New York.

Physicists, metallurgists, radio chemists and reactor engineers will find opportunities to work on this and other interesting reactor concepts at B&W. Address inquiries to W. F. Porter, Personnel Manager, Atomic Energy Division, The Babcock & Wilcox Company, 1201 Kemper Street, Lynchburg, Va.; or phone collect, VIctor 6-6521.

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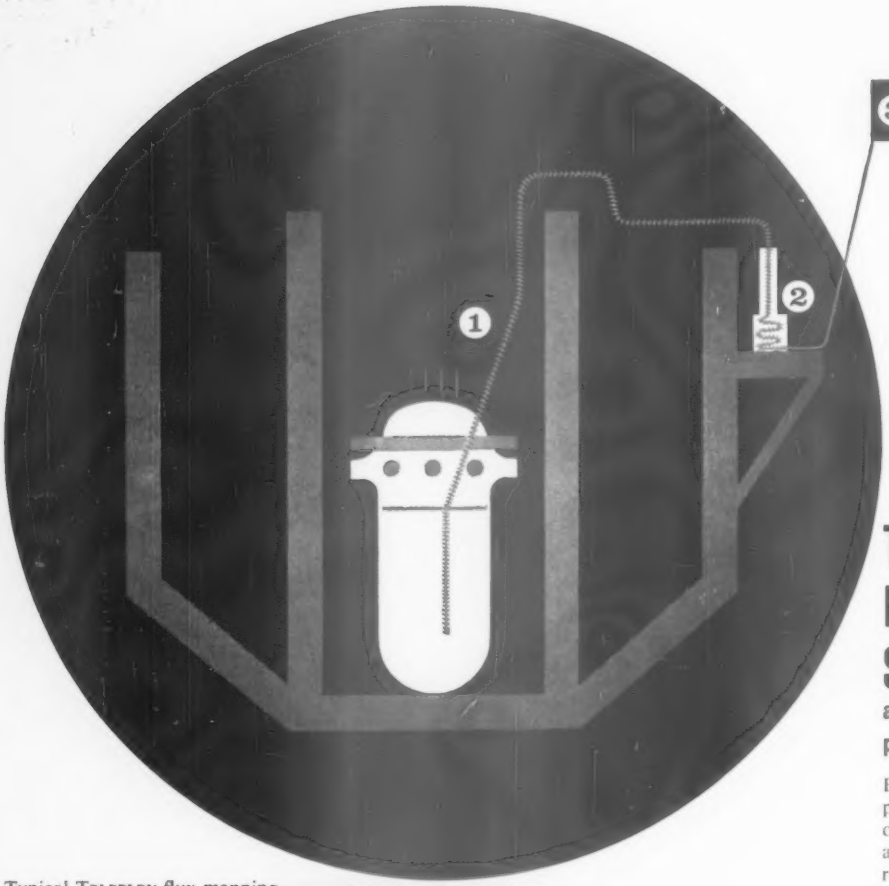
NUCLEAR POWER APPLICATIONS
AE 83
Vol. 19, No. 3 - March, 1961



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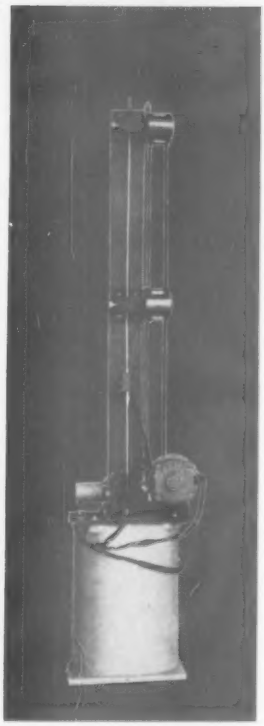
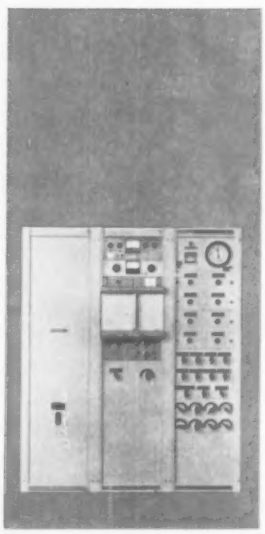


2. Electro-mechanical drive comprised of specially-hobbed wheel, gearmotor and compact cable-storage magazine.



3. Remote control system includes counters, readout and recording devices; may be located anywhere.

TELEFLEX FLUX-MAPPING SYSTEMS give speedy, accurate core observations, power distribution control

Every feature of the TELEFLEX System points toward more effective control of reactor power capability. This advanced system produces accurate, reliable flux level measurements, and quickly . . . a complete map can be obtained in approximately one hour. As a result of more exact understanding of fuel burnup and control rod programming, more economical refueling techniques and more efficient core power distribution at all power levels is possible.

The TELEFLEX System is a proved electronic-mechanical package, completely integrated and automatic. The principal component is TELEFLEX flexible cable, providing the means for unlimited accessibility to remote, normally inaccessible areas. The TELEFLEX System inserts flux wires into core thimbles, regulates wire exposure, automatically retracts exposed wires, passes irradiated wires through a counter-readout device, records activity of each wire and its accurate location.

The TELEFLEX System is basically simple, and lends itself to many reactor design configurations. Possibilities have by no means been exhausted. For some idea of all that TELEFLEX has to offer you, get in touch with TELEFLEX nuclear-trained engineers and research people.

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NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

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She's a Beauty!

The lovely setting in which the Yankee reactor has been located (look again at our four-color cover, the first such one in our history) has roused a mood of appreciation in us that extends to the reactor itself. Not only is Yankee in beautiful surroundings but the plant itself is a beauty, we feel. The six-page foldout on page 53, (ninth in our continuing series describing reactors as-built), will show you some of the reasons for our enthusiasm. But beyond that the plant was built ahead of schedule and—wonder of wonders—below budget (see p. 59).

Yankee represents the second generation of pressurized-water reactors and shows important improvements over its predecessor, Shippingport. What with the AEC's 10-year program for reactor improvements and the Southern California Edison plans for up to four large, third-generation PWR's, only a hard-bitten realist would refuse to believe that economic nuclear power is just around the corner. If they all get sited as handsomely as Yankee, touring the nation's many power-reactor sites in the late 1960's will be a pleasure indeed.

More on Zircaloy

We commend to your attention the article by Robertson and Notley on p. 77; it tells of favorable test results with Zircaloy-clad oxide fuel having a nonnegligible amount of fluoride in the UO_2. It's part of our continuing attention to an important question for the nuclear industry, namely the suitability of Zircaloy as a cladding material for high-temperature water reactors. As was discussed in our pages recently ("Zircaloy Cladding Performs Well in PWR" by B. Lustman, et al., NU, Jan. '61, p. 58) the difficulties encountered at the Dresden reactor have cast a pall over Zircaloy. Since General Electric, as the reactor builder for Dresden, is so intimately involved we have asked them for a statement of their position, which appears with the Robertson article. To round out your picture be sure to read the comments of Milton Edlund of Babcock & Wilcox and William Shoupp of Westinghouse that appear in our Nuclear Reactions (letters to the editor) column this month.

Speaking of letters to the editor, we wish you'd write us more often—as suits an industry full of dynamic people and interesting controversies.

We Were There

The closing date for this column is such that we were not able to comment last month on our own coverage of the SL-1 accident that occupied most of the news section in that issue. We feel the SL-1 accident is of extreme interest to all of our readers and have followed up the news-type coverage of February with an eight-page technical presentation (p. 62) based on a talk given by AEC's Director of Reactor Development Frank Pittman. Even as these lines are being written we're waiting on release on the interim report of the Board of Inquiry into the Idaho accident and hope to include some of it, too. When the Board's final report is submitted (which may not be for many weeks) we will transmit it to you as another of our Official Accident Reports. Our policy, expressed editorially back in May, 1956: reactor accidents are everybody's business.

—The Editors

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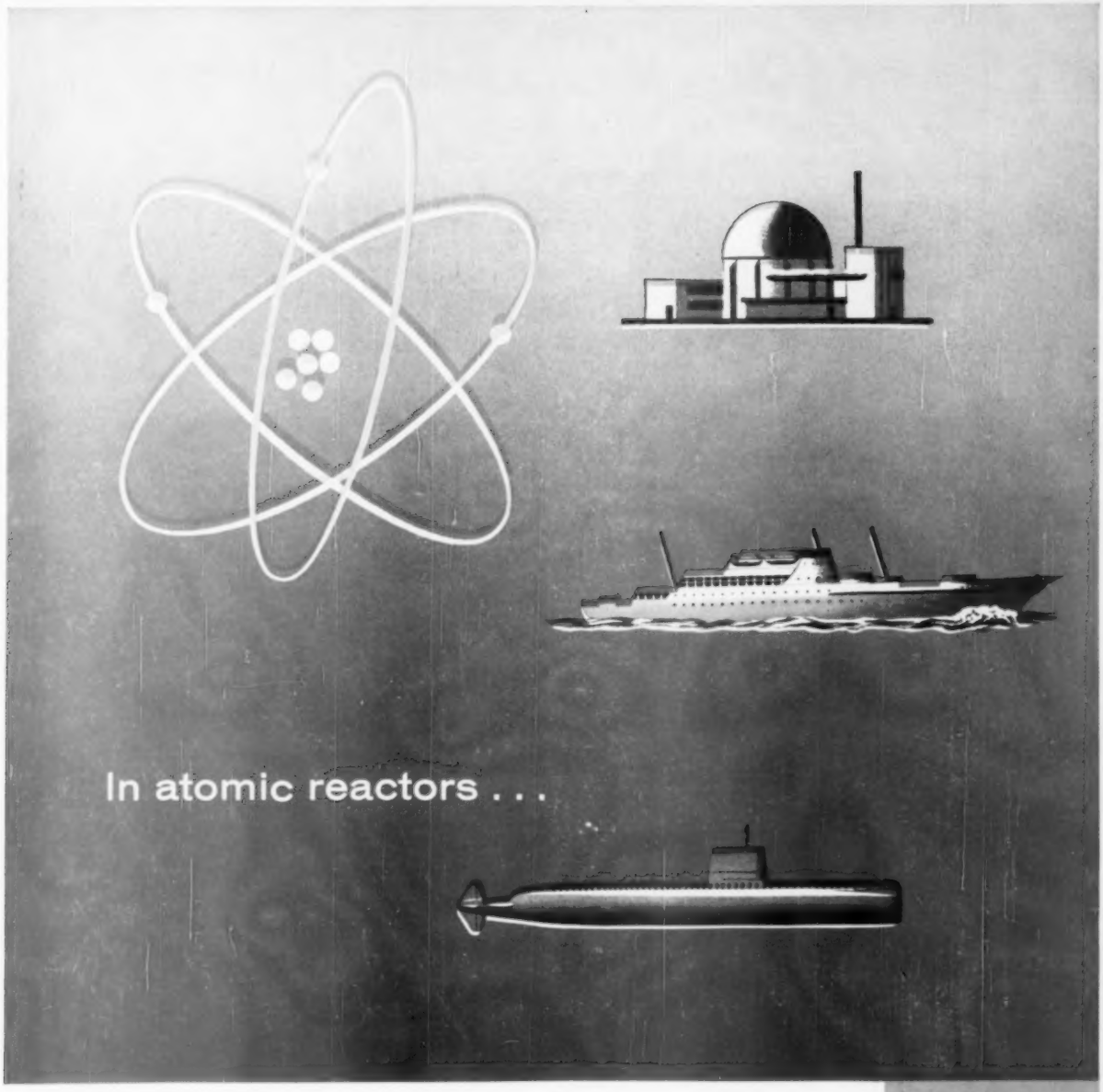

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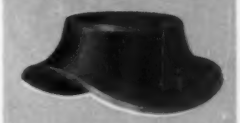

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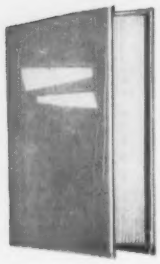

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PLASMA PHYSICS

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NUCLEAR REACTIONS

Edlund, Shoupp on Zircaloy

DEAR SIR:

The status of Zircaloy fuel cladding for civilian power reactors is one of the most important unknowns if not the most important unknown, facing the atomic energy industry at this time. There is a real question as to whether water reactors can be made economically competitive without the use of a low-cross-section cladding material such as Zircaloy. At the present time, as Lustman (NU, Jan. '61, p. 58) points out, Zircaloy-2 has been successfull in Shippingport. This experience, in addition to results of numerous tests performed at various laboratories, shows that Zircaloy-2 can be used in power reactors under certain limiting conditions of temperature, heat flux and operating time.

A complete perspective on Zircaloy cladding must take into account the results of tests already performed on Zircaloy-4; there is substantial evidence that the hydrogen pickup in Zircaloy-4 is considerably less than that of Zircaloy-2. Further confirmation of the reduced hydriding of Zircaloy-4 should permit operation at temperatures, heat fluxes and operating lifetimes required for lower fuel costs.

Some experiments indicate the possibility of suppressing the hydriding reaction by maintaining an excess oxygen concentration in the coolant water. This, of course, raises questions with respect to other materials in the primary system.

—M. C. EDLUND,
Manager, Development
The Babcock & Wilcox Co.
Lynchburg, Virginia

DEAR SIR:

The use of low cross section materials, such as Zircaloy, for fuel element cladding and as a reactor core structural material is necessary where neutron economy is at a premium. This is obviously true in reactors such as the seed and natural uranium blanket type used in the Shippingport reactor and in the D_2O cooled and moderated CVTR pressure tube reactor.

For slightly enriched reactors, the loss of neutrons to the higher absorbing clads such as stainless steel can be compensated by increased enrichments that tend to increase the inventory and burnup costs. However, fabrication costs in UO_2 pellet and metal tube geometries are less for stainless steel than for Zircaloy. At present expected lifetimes, fabrication costs and material loss rates, stainless steel appears to be more economical on an overall fuel cycle basis.

Certainly good zirconium has been and can be obtained; however, when the quality requirements are met in the longer lengths required in many core designs, the yield tends to decrease. Nevertheless, as more experience and production is realized, we expect to obtain Zircaloy for such applications at a price that will make its use economically sound. It appears also that the use of Zircaloy IV can markedly decrease the hydrogen pickup thus minimizing hydriding effects thus relieving one of the few remaining technical concerns.

It should be noted that significant success is being achieved in reducing

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the thickness and quantities of structural and cladding stainless steel used in UO_2 slightly enriched reactor cores. In addition, simpler and less expensive processes such as brazing are more adaptable to stainless steel than Zircaloy. Thus, the core designer has more design latitude with stainless steel. Generally, this tends to allow simpler structures and less expensive fabrication costs. These effects lead to increased requirements for cost reduction and quality control to make the use of Zircaloy competitive.

At this time, we feel that the economics are more favorable to stainless steel for slightly enriched UO_2 cores using rod geometry. On the other hand, we expect to use Zircaloy as a cladding material in the future for certain long life economical cores. As time goes on and as the long time use of Zircaloy is further verified and as inexpensive means are developed to use it, Zircaloy clad fuel can be fed into the reactor systems now designed for stainless steel. In other words, the use of stainless steel at this time does not prejudice replacing it with Zircaloy at a later date.

—W. E. Shoupp
Technical Director
Westinghouse Atomic Power Dept.
Pittsburgh, Pa.

Seawolf Sodium System OK

Dear Sir:

The article "Trends in Sodium Equipment," by R. W. Dickinson and J. B. Williams, appearing in the January, 1961, issue perpetuates a misconception concerning the sodium reactor in the submarine Seawolf.

The superheater leakage between the steam side and the monitoring space was, indeed, due to "a corrosion-induced metal failure," but the cause was traced to the chloride content of the steam, which had affected the stainless steel chosen for this service. To correct this difficulty without replacing the superheaters, the steam flow was diverted directly to the turbines.

During the very satisfactory first core lifetime of the Seawolf (see p. 77 of your September, 1959, issue), which included an underwater stay of two months, sodium continued to flow through the superheaters without incident. In fact, the reactor compartment was sealed after the early trial runs and no further maintenance was required.

—Peter J. Davis
Division of Reactor Development
U. S. Atomic Energy Commission
Germantown, Maryland

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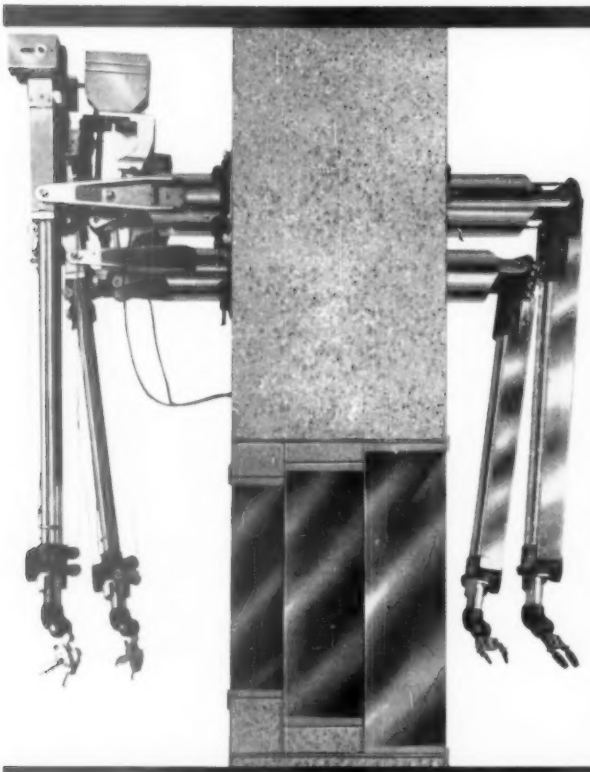

FEATURES—

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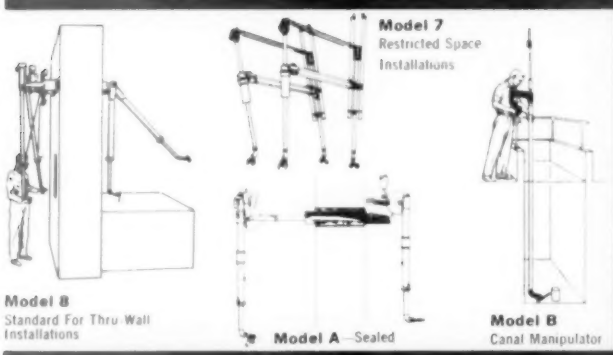

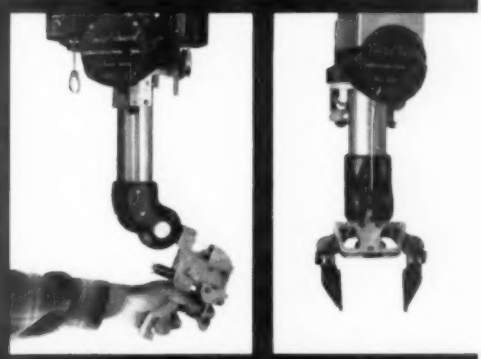

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New top for the Shippingport reactor

By the Ohio River at Shippingport, Pa., the United States' first full-scale central station atomic power plant devoted exclusively to civilian needs continues to generate electricity for the Pittsburgh district. In operation since 1957, Shippingport's reactor core received its second "seed" fuel early in 1960. The pioneer atomic plant is a joint project of the Duquesne Light Company and the Atomic Energy Commission.

The nuclear portion of Shippingport was designed and developed by Westinghouse under the direction of and in technical cooperation with the Naval Reactors Branch of the Atomic Energy Commission. The work was done at the Bettis Atomic Power Laboratory which Westinghouse operates for the AEC.

U. S. Steel's Homestead Plant supplied the forgings for the closure-head assembly needed to accommodate a new and higher power core developed by the Bettis Laboratory for Shippingport. As furnished, the 3-piece assembly weighs 81 tons—and every ounce of these USS Quality Forgings was cast, forged, machined and tested to meet the most rigid specifications.

The reactor's new closure-head assembly for Core 2 consists of a dome, torus, and head flange. The largest piece—the head flange—weighs 41 tons. To insure the highest degree of quality from the start, it was electric-furnace melted from a Ni-Cr-Mo alloy steel, then teemed into a 180-ton ingot in U. S. Steel's vacuum-casting facilities. After top and bottom discard, it was forged to an 85″ octagon; then it was upset to 60″ in height. Next a 30″ hole was punched in it to provide for mandrel forging. This hole was later opened up to take a 36″, and finally a 54″ forging bar. At this point the ring was flattened to 43″, the bar was again inserted in the center and the ring was mandrel-forged to its final dimensions—159″ overall diameter, 98″ interior diameter, and 42 1/2″ high, as shown in the big picture. It then weighed 83 1/2 tons and was ready for heat treating and preliminary machining. Final machining reduced the flange's shipping weight to 41 tons.

The torus, or "transition ring," was manufactured from the same grade of steel in the same careful, expert manner. It weighs 23 tons after final machining.

The dome is hollowed out on the inside and has a relatively small hole through its middle. This hole provides a refueling port; separate openings for control rod mechanisms were bored later. The dome was machined on our 20′ vertical boring mill with the aid of an electronic contouring machine. Final weight of the dome: 17 tons.

Dome, torus and flange were painstakingly tested and inspected every step of the way. Tests included ultrasonic inspection, tangential tension tests, Charpy V notch impact tests, grain size tests, bend tests and magnetic particle inspection.

U. S. Steel has the capacity, the men, and the equipment to manufacture quality forgings like these, whether they be rings, flanges, domes, pressurizers, tube sheets or other such nuclear and power plant components. And the very same men and equipment will be working on *your* order. For a free folder on USS Nuclear Forgings, write United States Steel, 525 William Penn Place, Pittsburgh 30, Pennsylvania.

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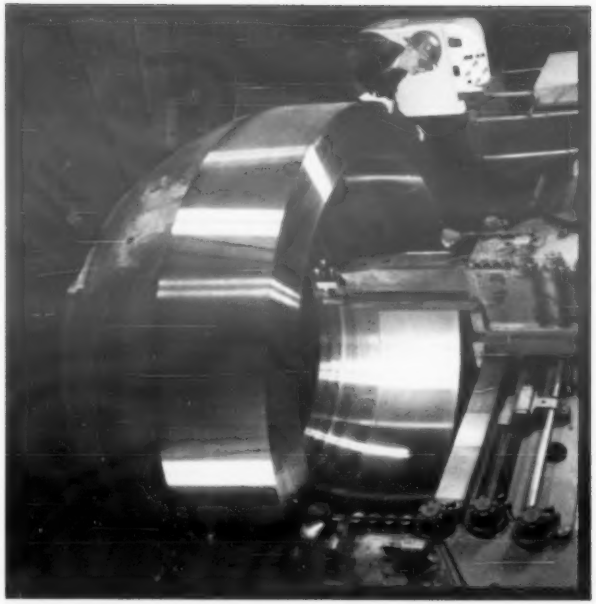
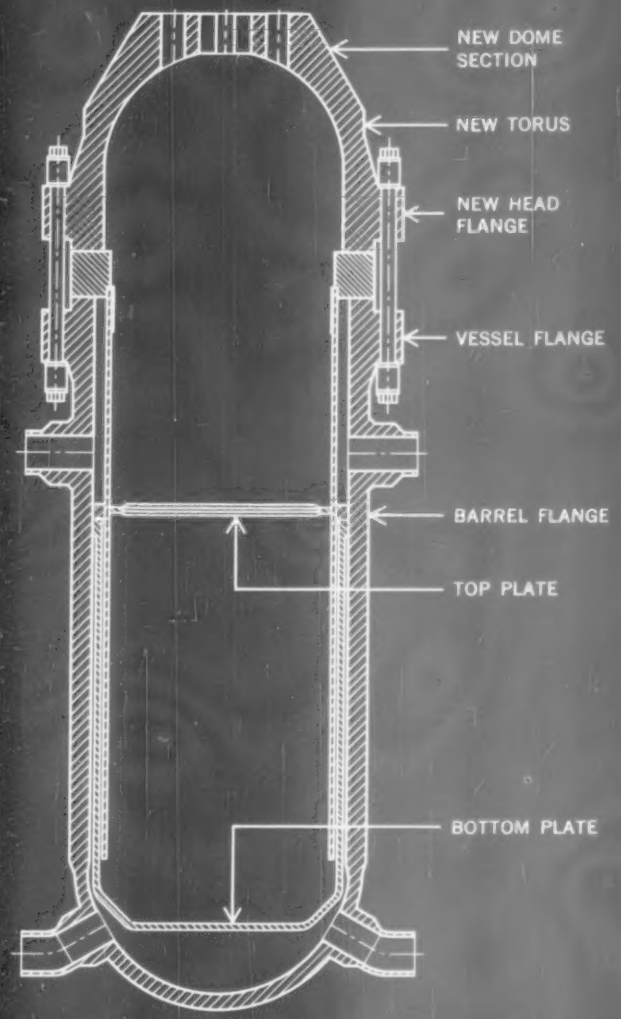
Photos, top to bottom—
head flange about to be quenched;
torus being contour machined;
ultrasonic inspection of dome.



Core 2

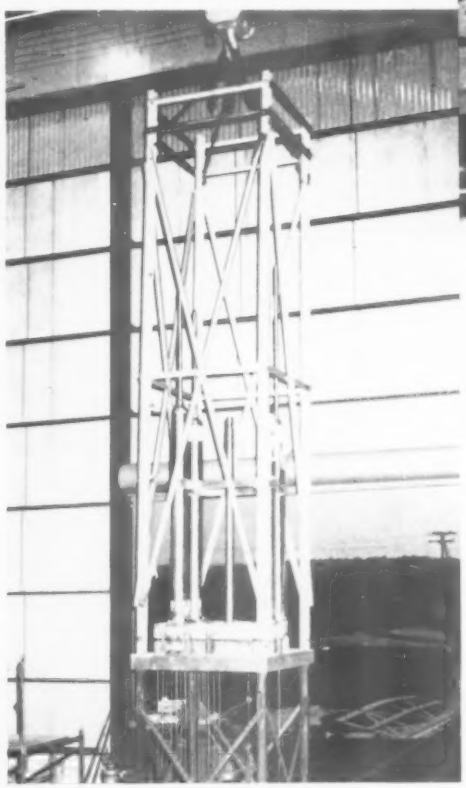
FORGED COMPONENTS



Since the three parts of this reactor vessel head—dome, torus and flange—will be welded into a single unit, there can be no allowance for failure. Every square inch of these three USS Quality Forgings were painstakingly manufactured and carefully inspected during and after the manufacturing process to assure perfection. The men, the forging facilities and the inspection equipment are available to you if you need forgings that must be as close to perfection as we can make them.

A&S SALUTE

A. & S. fabricated, machined, assembled, and tested the instrumentation support structure under the supervision of Westinghouse and YANKEE ATOMIC ELECTRIC CO.



COMPLETED TELESCOPING ASSEMBLY . . . 40 feet high, 8 feet square . . . ready for installation. Here, the 22 flux wire thimbles which extend into the core, are in lowered position.

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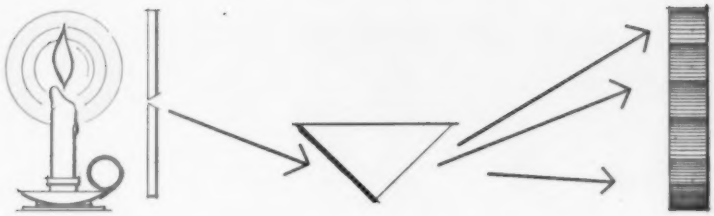

IN OPTICAL SPECTROSCOPY . . .

photons are separated by altering direction of travel as a function of photon energy. Measurement precision depends upon the quality of optical component.

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photons are not separated. Photons of different energies produce electrical signals of different amplitude. Measurement precision depends upon the quality of the pulse amplitude distribution analyzer.

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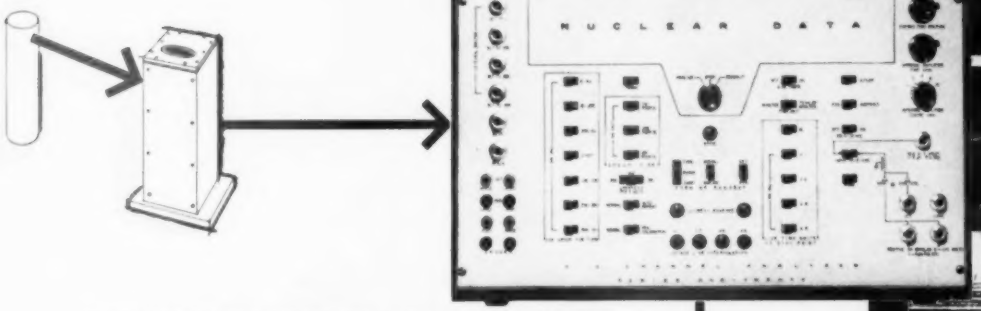

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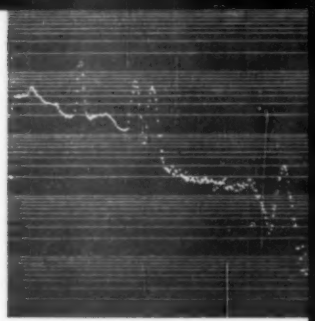

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A thermally Regenerative Fuel Cell to light small cities, power magneto-hydrodynamic devices, submarines and space platforms . . .

These are some of the nuclear projects in progress at Allison, with several under government contract.

In their research and development efforts, our atomic scientists and engineers employ such facilities as a vacuum chamber which simulates pressures at altitudes in excess of 200 miles; physical chemistry, solid-state physics, metallurgical and materials laboratories; a liquid metal loop; analog and digital computers and many other research tools. Their efforts are aided by American and European consultants, our Scientific Advisory Committee, plus every resource General Motors possesses.

Whether your problem is concerned with the heavens, the earth or the oceans, Allison has the will and—if it can be solved—the way to solve it. We're doing it for others, we could do it for you.

Shown is heat exchanger section of a nuclear- or solar-powered Stirling-cycle engine under development for space and terrestrial power systems.

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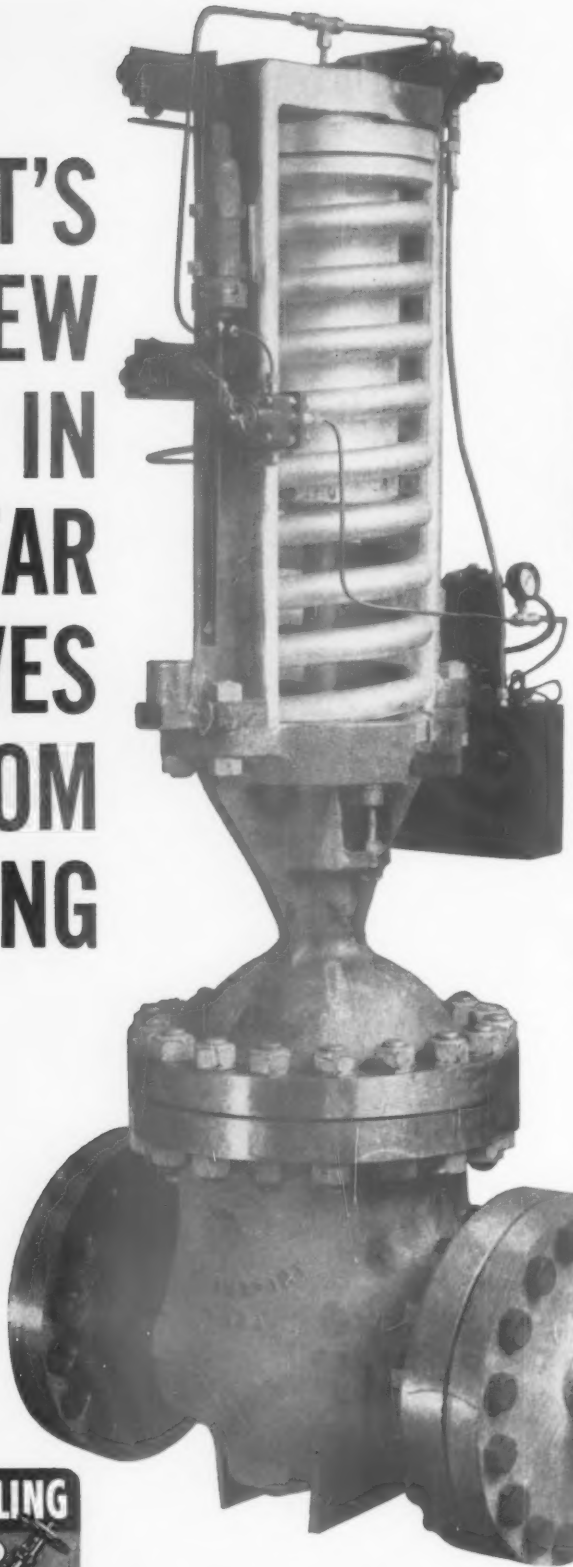
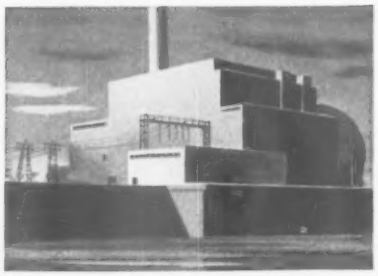
WHAT'S NEW IN NUCLEAR VALVES FROM DARLING





Automatic quick-opening valves for nuclear reactors

Here you see a special valve developed by Darling. Its primary function is to provide fast, automatic opening in a nuclear system.

This is but one of a number of nuclear valves being produced by Darling. Others include stainless steel valves and valves for control of demineralized water.

Send us *your* specifications on nuclear valves for our recommendations and quotes.

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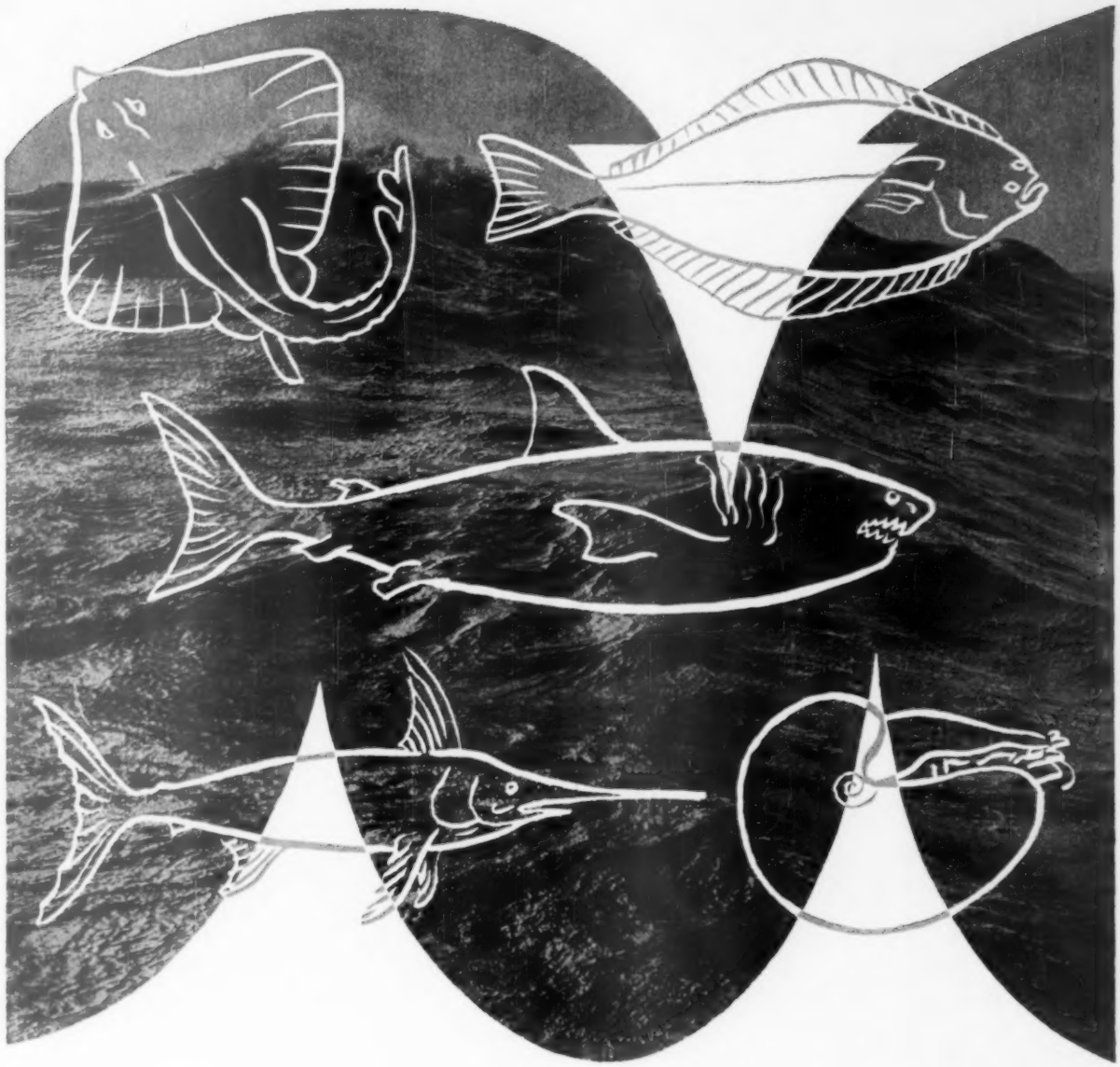

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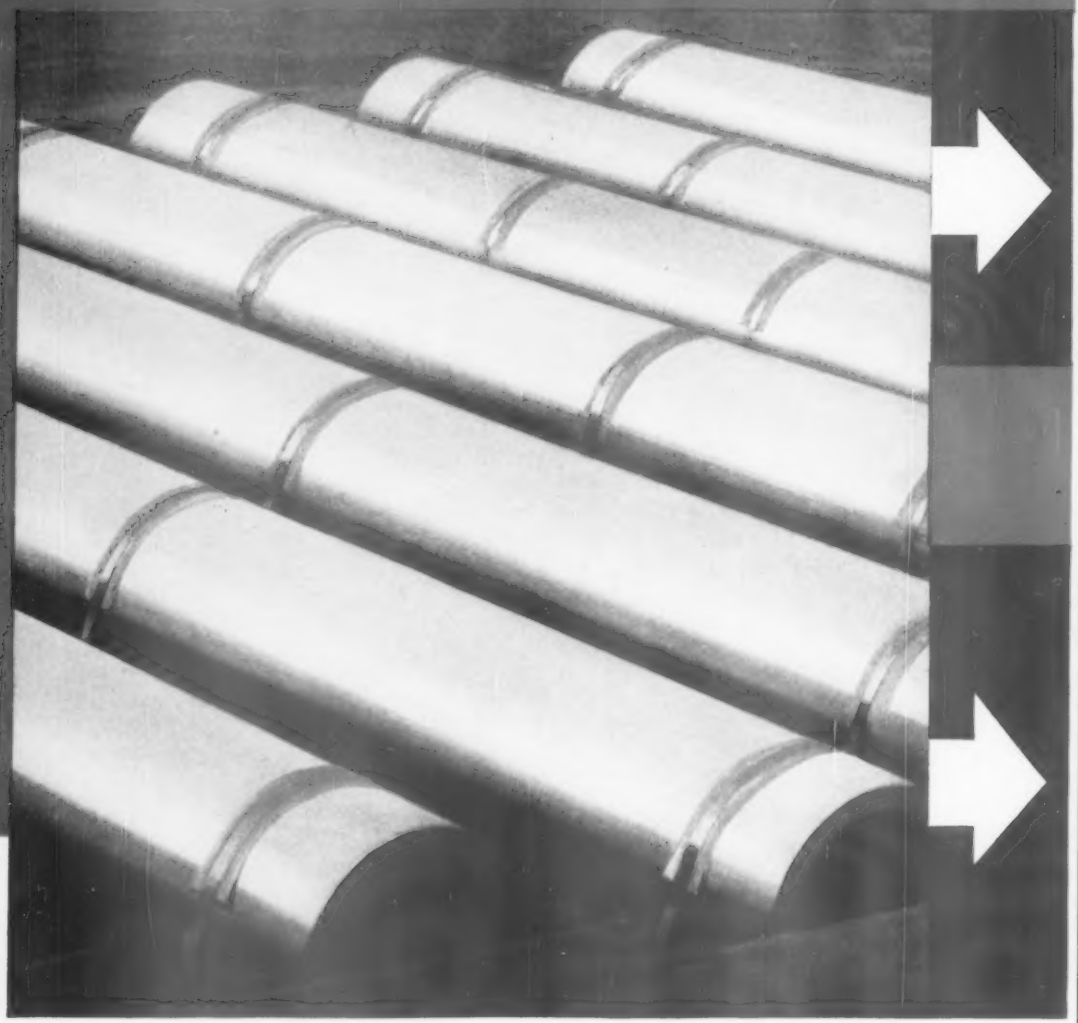

Centrifugal stainless steel castings readied for shipment by U.S. Pipe

The Government's new SPERT III nuclear plant at the National Reactor Station near Idaho Falls, Idaho, operating since December, 1958 to study nuclear reactor safety, uses U.S. Pipe's centrifugally cast stainless steel pipe for its coolant system.

SPERT III is classified as a high pressure, high temperature, light water moderated and cooled reactor. Its versatility permits transient tests under various initial conditions of pressure, temperature, and coolant flow. For example, pressures ranging from atmospheric to 2,500 psi and water temperatures from 68° to 668° F.

Another new nuclear power plant, engineered and constructed by Stone & Webster for Yankee Atomic Electric Company, is using centrifugally cast stainless steel heat exchanger shells made by U.S. Pipe and fabricated by the Southwestern Engineering Company in Los Angeles, Calif.

Stainless steel, centrifugally cast, made to rigid specifications, may be the answer to your piping or heat exchanger problem. For more information, write or call:

centrifugally cast stainless

REQUIREMENTS OF NUCLEAR AND COOLANT SYSTEMS

Shop-fabricated heat exchanger shells of centrifugally cast stainless steel ready for shipment to the Yankee Atomic Electric plant at Rowe, Mass.

Subassemblies of primary coolant piping of centrifugally cast stainless steel being installed in SPERT III.

ASA PRESSURE PIPING CODE STATUS

Approval has been granted under this code for the use of centrifugally cast austenitic pipe for nuclear piping by Nuclear Case N-9. This case appeared in the April, 1960 issue of MECHANICAL ENGINEERING. Reprints on request.

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PLUTONIUM FUEL PROGRAM

Newly completed NDA Facility to develop PU-U-Carbide fuel elements

NDA has just completed installation of a new Plutonium Handling Facility at its Pawling Laboratories to carry out a prime contract for plutonium-uranium-carbide fuel development as part of the AEC's Fuel Cycle Development Program.

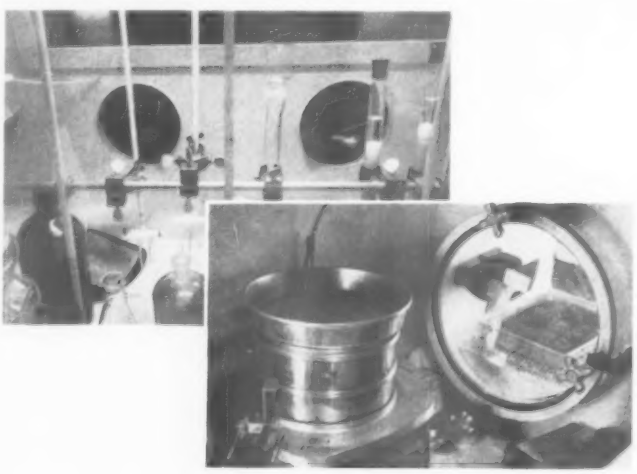
The objective is to develop fuel elements capable of producing economically attractive nuclear power at the earliest feasible time. Plutonium has important potential but its fuel characteristics must be documented through research and development, such as that now going on at NDA. Current efforts encompass a wide variety of investigations, ranging from fuel element conceptual design and fabrication through fuel irradiation and evaluation, and irradiated fuel reprocessing.

This plutonium fuel program is but one example of the many challenging projects now going forward at NDA, utilizing a skilled team of scientists, engineers, technicians and supporting personnel at the company headquarters in White Plains and at its Pawling Laboratories.

It takes the experience of many years and many people to achieve the valuable goal of utility through application of advanced technology. For a truly professional approach to research, development and application, look to NDA, where tomorrow's advances are being worked on today.

Current and prospective contracts at NDA involving the AEC, NASA, the Departments of the Army, Navy and Air Force, and private industry, provide a healthy growth climate and career opportunities for qualified scientists and engineers. Apply a professional approach to your career — research these opportunities for you at NDA. Write in confidence to Director, Professional Personnel.

Project engineer at one of glove boxes where actual work with plutonium is performed. Facility contains an interconnected series of metallurgical boxes, a series of chemistry boxes, hoods and other equipment for packaging, handling, air and inert gas circulation.



Interior view of one of the chemical boxes (above), and one of the metallurgical boxes, showing interconnecting passageway. All boxes and hoods are under negative pressure with inert gas atmosphere.

NDA NUCLEAR DEVELOPMENT CORPORATION OF AMERICA

WHITE PLAINS, N.Y. TEL. WH 8-5800 / NDA EUROPE 31, RUE DU MARAIS. BRUSSELS. BELGIUM

Crisis Over Reactor Siting; New AEC Guide May Help

The growing problem of reactor siting in the nuclear power industry took on the proportions of a crisis last month. It began to appear as though something would have to be done soon about a problem that was fast becoming a millstone threatening to strangle nuclear power before it reached maturity.

Publication by AEC of its new proposed reactor siting guide climaxed a series of rapid-fire events that focused attention on the problem. In the fortnight before the guide was issued:

1. It was learned that the Southern California Edison project for a 360-Mwe pressurized water power reactor—the industry's main hope and symbol of an upturn out of the doldrums—was in serious doubt because of a site problem (*see p. 25*).

2. The Los Angeles Dept. of Water & Power project to build, jointly with AEC, a 50-Mwe boiling water plant, vanished when LADWP withdrew its proposal following an adverse site report by the Advisory Committee on Reactor Safeguards (*see p. 25*).

Background on Siting

Most of the other problems besetting the industry last month were siting problems or had their siting angle. Overshadowing them all were two that had been dragging since 1956:

• **The Fermi case:** It seems more and more as though all in the nuclear field were keeping one uneasy eye cocked on the severe white marble Greek temple in Washington whence will issue, perhaps in April, the U. S. Supreme Court's decision on Fermi. This is awaited to establish once and for all whether or not AEC was justified in granting a construction permit for the Fermi fast breeder near Detroit, whether or not that permit is valid, and whether or not AEC may allow reactors to be placed "near" (how near?) "large" (how large?) population centers without "compelling reason"—as laid down in a lower-court decision.

To this last question AEC's proposed siting guide offers tentative answers; but—perhaps with deliberate prudence—AEC allowed an unusually-long 120-day waiting period for public comment before the guide goes into effect.

• **AEC's regulatory organization:** Four studies await consideration by the new AEC leadership as action may finally be taken this year in the direction of separating AEC's regulatory from its promotional and operation functions (*see p. 27*). JCAE has scheduled a hearing on this subject for March or April.

AEC's Siting Guide

The new criteria are the indirect result of three years' work, and the direct result of a concentrated effort by a special staff named last spring.

A first attempt to draft reactor siting criteria, published May 23, 1959, ended in its withdrawal by AEC after industry had objections.

This time industry reaction as surveyed by NUCLEONICS seemed to be mixed—and split on the basis of human temperament rather than along lines of geography, type of business, or special interest. For some congratulated AEC for putting out a guide that was at last something definite, while others castigated the same document for being vague and "interlarded with weasel clauses." The preponderant opinion was favorable, however.

Provisions. The brief document (only seven pages long, plus a four-page appendix) attempts to provide formulas for those factors in site selection that are quantitatively measurable, while listing the impalpable factors that will also be taken into consideration in applying the formulas. Three measures for selecting location of a reactor are defined: exclusion area, low-population zone, and population-center distance (see definitions on p. 24). The first and third are classical measures, the second is new—in formulation if not in underlying concept. The table at right gives a minimum number for each of the three for reactors of varying power from 10 to 1500 Mwth.

Special consideration is provided for "inherent characteristics and specifically designed safeguard features of the reactor . . . plus its purpose and method of operation." Thus a channel is provided that can presumably be used to give credit for pressure suppression or other safety-engineering features; these would justify less isolated sites. On the other hand, the criteria "apply primarily to reactors of a general type and design on which experience has been developed . . . For reactors which are novel in design, unproven as prototypes, and do not have adequate theoretical and experimental or pilot plant experience, these criteria will

Estimates of Reactor Distances*

Power (1Mwth)	Excl. Dist. (mi)	Low Pop. Zone (mi)	Pop. Ctr. Dist. (mi)
1500	.70	13.3	17.7
1200	.60	11.5	15.3
1000	.53	10	13.3
900	.50	9.4	12.5
800	.46	8.6	11.5
700	.42	8.0	10.7
600	.38	7.2	9.6
500	.33	6.3	8.4
400	.29	5.4	7.2
300	.24	4.5	6.0
200	.21	3.4	4.5
100	.18	2.2	2.9
50	.15	1.4	1.9
10	.08	.5	.7

How Existing Reactors Compare*†

	Power (Mwth)	Excl. Dist. (mi)	Low Pop. Zone (mi)	Pop. Ctr. Dist. (mi)
Dresden	630	0.5	11	15
Indian Point	585	0.3	2	2
Yankee	485	0.5	10	25
Fermi	300	0.6		25
Hallam	240	0.25	5	10
Shippingport	225	0.3	1.5	7.5
Sioux Falls	200	0.5	3.5	3.5
Humboldt Bay	163	0.2	2	4
Big Rock Pt.	160	0.5	20	40
Peach Bottom	115	0.6	5	21
EBWR	20–100	0.8	5	5
EGCR	85	0.73	4	4
Elk River	64	0.4	5	35
CVNPA	63	0.5		27.2
VBWR	50	0.36		12
BONUS	50	0.3	2	13
Piqua	45	0.14	1	5
SRE	20	1.4	5	10
Saxton	20	.5	.54	30
SM-1 (Ft. Belvoir)	10	2	2	10
HRE-2	2	0.2	6	6

* Distances are defined in box on p. 25.

† These numbers were compiled in a 1½-day telephone survey; while they are as accurate as we and those we contacted could make them in limited time, the table is intended for purposes of comparison and should not be regarded as final or official.

need to be applied more conservatively."

Another broad exception, seemingly aimed at keeping reactors out of big city areas even if the formulas should by some chance seem to justify it, says, "Even if a more serious accident (not normally considered credible) should occur, the number of people killed should not be catastrophic."

Industry Reaction. A majority of those questioned by NUCLEONICS feel the criteria are helpful, and some said they were frankly surprised by its reasonableness and found it "better than expected." Several pointed out that it was specifically labeled a "guide" and not a rule; and that it was a mixture of measurable criteria and those that cannot be quantitatively defined.

Concern was expressed over siting of large reactors for large load centers. One pointed out that an 18-mi population center distance (for a 1500-Mwth reactor) may be impossible to find near any load center; said another industry leader, "I worry that we seem to start by saying we have to be 18 miles from large population centers for large plants—somehow over the years we will have to get that down." Here some saw the consideration given to engineering design as the way out: "Design is the first line of defense," said one. "You tell us the exposure, and we'll design to it."

Critics in some cases felt that the guides were too definite, arbitrarily, in an area where too many factors cannot be expressed in numbers; in others, that the field has developed sufficiently to have permitted a greater degree of definiteness. Some question areas brought up: what happens "when they build around you"? what help—if any—is there for the small municipal utility whose economics (and often also whose charter) wants it to limit operations within its municipal system area? what is a "catastrophic" death-toll? how calculate the low-population zone? (the last was frequently mentioned as a "fuzzy" area); why are test reactors thrown in with power?

Definitions of Distances in AEC Siting Guide

Exclusion area "means the area surrounding the reactor, access to which is under the full control of the reactor licensee. This area may be traversed by a highway, railroad or waterway, provided these are not so close to the facility as to interfere with normal operations, and provided appropriate and effective arrangements are made to control traffic on the highway, railroad or waterway, in case of emergency, to protect the public health and safety. Residence within the exclusion area shall normally be prohibited. In any event, residents shall be subject to ready removal in case of necessity. Activities unrelated to operation of the reactor may be permitted in an exclusion area under appropriate limitations, provided that no significant hazards to the public health and safety will result."

A reactor should have an exclusion area "of such size that an individual located at any point on its boundary for 2 hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure."

Low population zone "means the area immediately surrounding the exclusion area which contains residents the total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in the event of a serious accident. These guides do not specify a permissible population density or total population within this zone because the situation may vary from case to case. Whether a specific number of people can, for example, be evacuated from a specific area, or instructed to take shelter, on a timely basis will depend on many factors such as location, number and size of highways, scope and extent of advance planning, and actual distribution of residents within the area."

A reactor should have a low population zone "of such size that an individual located at any point on its outer boundary who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure."

Population center distance "means the distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents." [There were 673 cities of 25,000 population or more in the U.S. in 1960.]

A reactor should have a population center distance "of at least 1⅓ times the distance from the reactor to the outer boundary of the low population zone. In applying this guide due consideration should be given to the population distribution within the population center. Where very large cities are involved, a greater distance may be necessary because of total integrated population dose considerations."

Site Woes: LADWP Drops Reactor, So. Cal. Edison in Doubt

Conflict between site economics and site safety, which has held up for a year one of AEC's fiscal '60 reactors and led to abandonment of another, last month struck sharply at two major nuclear power projects in Southern California. Indirectly—because of Marine Corps opposition—it cast a serious cloud of uncertainty over Southern California Edison's plan to build a 360-Mwe pressurized water reactors. And the conflict caused Los Angeles Department of Water & Power to withdraw its proposal to build a 50-Mwe boiling water unit.

In the former case, the question is whether or not Edison and its backers, including AEC, can obtain 90 acres of land in the Marine Corps' Camp Pendleton over Marine opposition. Edison has concluded that "there is no other [site] that would be attractive to us at the present time." In LADWP's case it was an adverse opinion by the Advisory Committtee on Reactor Safeguards regarding the utility's plans to develop a site at Haskell Canyon in Los Angeles County for nuclear stations.

The situation brings to focus one that has been building up for some time. AEC's Small-Size Pressurized Water Reactor has been stalled for a year, and its process-heat reactor for sea-water desalinization has been abandoned, as consequences of site, problems.

Last month the price tag on the differential in an actual case was disclosed: for the City of Jamestown, N. Y.—leading bidder for SSPWR—the cost of power at the optimum site that AEC and ACRS will approve is 2½ times greater than that at the economically optimum site (see below).

LADWP. On Feb. 3 LADWP notified AEC that it was withdrawing its proposal to build the 50-Mwe Improved Cycle Boiling Water Reactor because of threatened restrictions by ACRS on use of its 1100-acre site at Haskell Canyon 3 mi north of Saugus in Los Angeles County. ACRS had ruled on Jan. 14 that Haskell Canyon was suitable for the 50-Mwe ICBWR alone, but not for ICBWR plus four eventual 300-Mwe scale-ups that LADWP sees in its future. ACRS said the temperature inversion phenomenon of the Los Angeles basin (cause of the area's famed smog) could equally well trap a radiation escape cloud and hold it at low altitudes, and that this precludes the building of power complexes as large as LADWP envisages. (AEC's Nuclear Facilities Safety Branch—ex-Hazards Evaluation Branch—doesn't necessarily agree, feeling—on the basis of studies not yet completed—that if the site is safe for ICBWR, it should also be safe for adequately-engineered units up to 350 Mwe.)

Consequently Samuel B. Nelson, general manager and chief engineer of LADWP, wrote AEC acting chairman John Graham that his group could no longer justify the project. "The AEC restriction to a single-purpose use of the site would have increased the cost of the project beyond reasonable limits," Nelson said. (LADWP engineers estimated that this factor, plus other unanticipated fuel, maintenance and operation expenses, would increase the cost of ICBWR by $700,000 annually.) "The Department will now concentrate its efforts on finding an economi-

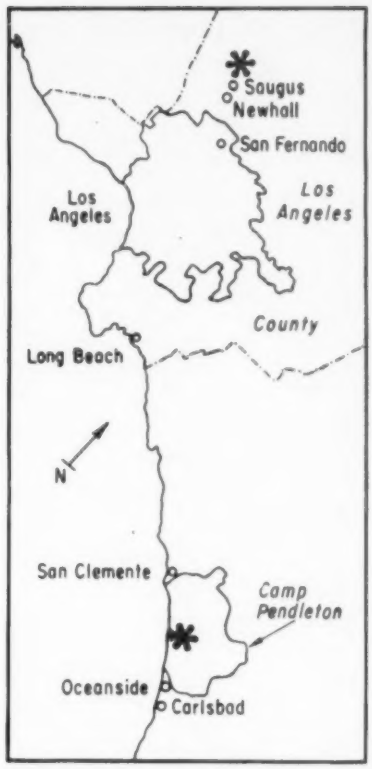
cal and acceptable nuclear site for a nuclear plant of possibly 300 Mwe size, to be built when it will be competitive with conventional power generating plants," Nelson said in a report to Los Angeles Board of Water and Power Commissioners.

LADWP and Pasadena Municipal Light & Power Dept. had planned to share equally both operating costs and $10-million toward capital costs. Pasadena joined LADWP in withdrawing the proposal.

The ICBWR project, now eight months behind scheduled construction start, already had been the subject of one of the strangest muddles in the history of the U. S. atomic program when AEC awarded the job of building ICBWR to General Electric, withdrew it, and finally reawarded it to Allis-Chalmers (NU, Dec. '60, 23). LADWP had preferred the GE design and wrote AEC prior to the reaward to plead on behalf of the "technically superior" GE reactor. Ironically Allis now finds itself with a sizable investment in preliminary design work threatening to vanish in a puff of smoke—just as happened to GE a few months earlier. Allis is hoping to interest AEC and one of the nine public power groups expressing interest in the improved 50-Mwe organic reactor (*see p. 31*) in its building ICBWR for them.

Southern Cal. Edison. The Marine Corps, which uses the 124,741-acre Camp Pendleton for training activities, told NUCLEONICS last month that it was flatly opposed to the site proposed by Edison—a 90-acre site in the center of the reservation, along the coastline. The Corps suggested that Edison consider a site in the northwest corner but this is felt to be too close to population centers and unsuitable topographically. Last month, Corps Commandant Gen. David M. Shoup declared: "We don't want anything to disturb our beachhead areas for [amphibious] training purposes. We don't want [the reactor] any place [on the reservation]." He noted that "this is a Navy Dept. matter" because the Corps is a part of the Navy but insisted that "the Marine Corps is not going to change its position."

AEC Undaunted. AEC, clearly eager to keep the project alive, revealed in a statement on the siting question (in answer to a NUCLEONICS query) that much more than a single reactor is at stake. "Southern California Edison," AEC said, "plans that the [360-Mwe] plant would be the first of four nuclear-powered generating units on one site." The Commission then went on to: **1.** discuss Edison's reasons for selection of the Pendleton site ("economics, location, and reactor-safety considerations"); **2.** disclose the "tentative" conclusion of the Advisory Committee on Reactor Safeguards and AEC's hazards staff that the site "would be acceptable for this plant"; **3.** point out that the Marine Corp's objections were based not on the nuclear aspect of the project but on opposition to any non-Marine project on the reservation; and **4.** disclose that former President Eisenhower had been briefed on the AEC-Marine Corps dispute before he left office.



ASTERISKS ON MAP SHOW (at top) LADWP's now-abandoned site in Haskell Canyon, and (bottom) Camp Pendleton site that Southern California Edison hopes to get

"The question of whether or not the nuclear power plant could constitute a significant interference with Marine Corps activities at Camp Pendleton," AEC said, "remains to be resolved. . . . The Commission is hopeful that arrangements can be made for use of the Camp Pendleton site without interference with the Marine Corps' activities and without establishing a precedent which might create future problems for the Marine Corps. After Chairman-designate (Glenn T.) Seaborg is in office, it is expected that the Commission will request further conversations with the Marine Corps and the Department of Defense, with the objective of resolving the site-selection question."

No Promising Alternates. A high Edison official said the utility, which has asked for a long-term lease, still hoped that something could be worked out at Pendleton. "We have looked at a number of sites and this one has been our first choice all along the line. At the moment, I don't think there are any others that are attractive in today's economics and that we could get safety clearance on. . . . If this site doesnt' work out, there is no other that would be attractive to us at the present time."

Edison has reached general agreement with Westinghouse on purchase of the 360-Mwe plant (NU Wk, 8 Dec. '60, 1); Bechtel Corp. would be engineering constructor.

The Cost of Safety. Last month in his annual report to the Governor, New York State's Director of Atomic Development disclosed that Jamestown's Board of Public Utilities had been willing to pay AEC (as reactor owner under second-round rules) for steam at the equivalent of 6.1 mills/kwh at a site within Jamestown city limits (to which AEC objected on safety grounds), but only 2.5 mills/kwh at a site outside the corporate limits of the city. "The city's willingness to pay only much lower charges for power from an out-of-town reactor site is attributable to its desire to absorb by this means the additional capital and operating expenses it would incur at such a site," the report explains. "These mainly have to do with extra distribution, substation, site development and site maintenance costs."

Moreover, Jamestown has suggested to AEC that "if the reactor as presently designed is considered to be not suitable for construction at the within-city site, then we urge that AEC consider modifying the design. It would appear that considerable modification could be accomplished at less expense to the total project than moving it to an alternate site outside the city."

LADWP, for its part, feels it would have to get power at 6.5 mills/kwh to make a project attractive. It was willing to pay a premium for nuclear power to get experience, and figured long-term cost of power from ICBWR at 9 mills provided it were later teamed with one 300-Mwe unit. But power costs would jump to 11.5 mills if the 50-Mwe plant were destined to operate as a single unit at the site, because of higher operation and maintenance cost per kwh, proportionately higher insurance and fuel costs, adding up to $700,000 extra a year. Not feeling it can afford this, LADWP is skipping the 50-Mwe step and looking for a suitable site for 300-Mwe units.

AEC Faces Reorganization Issue; 4 Reports Under Study

In a transitional period facing operation under a new Administration and a new chairman, AEC faces a number of major problems. One of the most fundamental is a question of its own internal organization—the long-debated question whether or not its regulatory responsibilities should be split off from its promotional and operational ones. Long at issue, the question appears to be coming to a head, and a number of proposed solutions are already receiving attention in Washington.

There are increasing demands that AEC be reorganized to eliminate basic inconsistencies in its duties and functions. These inconsistencies are apparent in AEC's three major functions:

- To operate its vast $7.5-billion physical plant, which develops and produces atomic energy for both military and peaceful uses.
- To promote a free-enterprise, private nuclear industry.
- To regulate the private industry it is supposed to promote—for the protection of the public.

These three functions vested in the same agency create for AEC and private industry conflicts which, unless solved, could delay or preclude the advent of economic nuclear power.

If and when Seaborg and the Kennedy Administration get around to trying to solve the problem, they will have at their disposal four separate studies being conducted by AEC, the Joint Committee, the Univ. of Michigan Law School, and Brookings.

AEC's reorganization study proposes that all regulatory functions now under the General Manager be placed under a Director of Regulation, who would report directly on regulatory affairs to the five-man Commission. Under the new organization, operational and promotional functions would continue to be administered by the General Manager.

The present Division of Licensing & Regulation and Division of Compliance would be split off from the present General Manager's line of authority, to be placed under the new Director of Regulation. The Division of Compliance would become an Office of Inspection under the new scheme and would incorporate such Office of Health & Safety staff as have duties in the regulatory field.

The reorganization proposal, if it gains the backing of Chairman Seaborg, will be coordinated with recommendations from the Joint Committee on Atomic Energy. It is understood that AEC will seek to have certain aspects clarified and formalized by law.

The Joint Committee's study was carried out by its staff with assistance from special consultants David F. Cavers of Harvard Law School and William Mitchell, former AEC General Counsel. The review is to be released as a staff study rather than a JCAE report representing views of individual Committee members. However, JCAE expects to conduct public hearings on the staff report and other recommendations on the AEC regulatory program.

The JCAE study explores the desirability of establishing a completely separate licensing board to handle nuclear facility safety regulation.

Now in the final stages of preparation, the study—prepared as a staff paper for JCAE—will propose a 3-man board to conduct reactor-licensing hearings and decide the cases. The members would be men of high technical caliber and prestige, appointed by the President (one complaint of the existing hearing-examiner system is that the examiners are legally-oriented and cannot bring out important technical factors). The 5-man Commission would retain its rule-making and policy-making functions but would look to the 3-man adjudication board for recommendations on licensing rules. The Advisory Committee on Reactor Safeguards would remain, but its role would eventually narrow to reviewing new reactor types.

The proposal differs from AEC's reorganization study in that: **1.** the board itself would make licensing decisions, leaving AEC free for policy and promotional work; **2.** AEC would employ both technical and legal experts at the hearing stage; **3.** the proposal would establish the germ for an eventual complete separation of licensing and promotional functions at AEC, when that makes sense.

The Univ. of Michigan Law School Atomic Energy Research Project has just completed probably the most ambitious and broadly-conceived analysis to date of AEC organization and regulation of private nuclear facilities. The exhaustive, four-part work has been circulated among interested atomic groups for comment. Its authors are Lee Hydeman and William Berman, both former AEC attorneys.

Recommendation: split of the present Commission into two agencies: **1.** an Atomic Energy Administration to be headed by a single executive with operational and promotional responsibilities; **2.** a three-man Atomic Energy Board to carry the regulatory duties.

The Brookings Institution Theoretical Analysis of AEC regulatory-safety problems is working toward the most unusual conclusions yet to come from the considerable attention the matter is now receiving.

The Brookings study differs from all others in its somewhat radical attempt to define and identify the "real process" involved in AEC licensing and regulation of reactors. Brookings research so far has found that emphasis would be misplaced if it were applied to the formal adjudicatory and rule-making procedures of regulatory programs. Instead, findings are that the regulating of reactor facilities stems primarily from "talk back and forth" and letters regarding safety and current technology between AEC's Nuclear Facilities Safety Branch staff and industry technicians.

The Brookings study is under the over-all direction of Prof. Marvin Bernstein of Princeton Univ. and will, with seven other case studies on regulatory problems, eventually be published in book form. Though the study will list its conclusions, it intends making no recommendation concerning AEC organizational changes.

It cannot be said yet that Joint Committee members will either endorse major AEC organizational changes or act to tighten up regulatory procedures within the present Commission framework. JCAE is aware of reactor siting problems and knows that some think governmental caution in this field is bogging down too many power reactor projects. For this reason, the committee staff has been instructed to perform its analysis of AEC licensing procedures, and hearings will be conducted later this year to receive testimony from private and government officials.

Rep. Chet Holifield (D-Calif.), the new Joint Committee Chairman, however, is cool to splitting AEC along Hydeman-Berman lines.

Says Holifield: "I question if the Commission should enter a broad field of regulation in peacetime efforts. As we get more reactors, we will need more regulation, more inspection, more watchfulness. That's why we passed an enabling law permitting the states to take over when they are qualified. They are training people but haven't yet the trained manpower to do it. I would like to see AEC get back to the job it was set up to do: to push development. But until the states qualify themselves to do regulation, we have to continue that on a federal level, and that's why I'm not pushing this [splitting AEC]."

Reactors for Sale: A Tour through the Nuclear West

The West—the frontier, traditionally, in American history—has more recently been becoming a magnet for a number of industries. The West has also been exerting a growing attraction on the nuclear industry. It beckoned General Dynamics, Aerojet-General and American-Standard into establishing their nuclear divisions in California; the move of General Electric's Atomic Power Equipment Dept. from Schenectady to San Jose five years ago was perhaps the most spectacular illustration. And already almost a decade earlier, the West's wide open spaces had lured the first plutonium production center and the nation's reactor testing station to the deserts of the northwest.

Here are some impressionistic snapshots of a tour through the Nuclear West based on a three-week, 8,000-mile trip by NUCLEONICS *News Editor John Kenton. It is limited—for lack of time—to the civilian reactor industry. It is limited in space, too, to a very few highlights at each installation.*

A second installment of this Western travelogue will appear next month.

Atomics International

Four principal lines of development are being pursued at the firm's extensive labs (Canoga Park) and test site (Santa Susana) just northwest of Los Angeles: sodium graphite, advanced epithermal, compact SNAP-type for space power (these three are closely related), and organic. The back-up and supporting research and development for these programs—in development of materials and techniques for their fabrication and use—is on a vast scale.

One of the major materials efforts is on uranium monocarbide, which AI sees as the only proper fuel to gain maximum effectiveness from the sodium graphite concept. It's hoped to be able to make the third core for the Sodium Reactor Experiment of UC, and some UC elements are to be tried in the second core, now about to reach full power. Core 2, chosen 4–5 years ago when thorium looked good compared to uranium, is of thorium-uranium metal alloy.

The firm is now higher than ever in its enthusiasm about sodium graphite. The studies for the ESUPRA project competition showed, AI says, that sodium graphite is now substantially cheaper. Moreover, although water reactors are given an edge on maintenance and accessibility, statistically one must expect to get some cladding failures—and thus fission products in the primary, reason AI's sodium enthusiasts. Now fission products are soluble in water but not in sodium—so that it turns out that the sodium plant has better accessibility than a water plant after clad failures.

Another switch as time goes on in the relationship of water and sodium plants is on expense. There is nothing peculiar to sodium systems that is expensive, AI insists: it's the materials for containing high temperatures. As water reactors reach desired higher temperatures, their gear will become more and more expensive too. Sodium costs can only come down; "we're better off because we have no corrosion problems—and low pressure. They haven't faced up to these things yet," says the sodium man. "Sodium is really a lot less sophisticated than water—there are only a few things to know about it."

The plant AI offered ESUPRA is a current status plant, not an advanced plant requiring a research-development program and based on a guess as to which way the technology will go. "We didn't even propose uranium monocarbide. We proposed what we think we can build right now." The SGR has come a *long*, long way since Hallam, AI feels ("Hallam is a very conservative reactor, a model T compared to the ESUPRA design").

Work in the SGR and OMR critical facilities at Santa Susana has slowed considerably because of the cutback in funds (and much of the organic work is done in Idaho, at OMRE); but the AETR critical, which just recently went critical, is going full ahead. The Advanced Epithermal Thorium Reactor concept is like a very advanced SGR, shooting at a full-scale, breeder plant on the line making economic power by 1972–75. Following a first phase of preliminary physics and paper studies, the program is now in Phase 2 (May 1959 to Jan. 1963) to establish the physics and the general feasibility of the concept from the physics standpoint, also to determine what economics are needed from the fuel to make the concept attractive. "If it doesn't change more than 5% from what we now believe on the basis of a few scattered experiments and paper work, we could get a breeding ratio a little better than one."

SOME OF MAJOR SITES in Nuclear West

The AETR critical will be the first facility outside AEC to use U^{235}; fuel studies will also be made on Th-U alloy, ThC-UC, and paste fuel. AI hopes to develop a suitable thorium alloy, ceramic or cermet. The most promising fuel now seems, on the basis of just paper work, to be a UC-ThC mixture, containing about 11% U^{235}. AI is also watching closely NDA's work on plutonium carbide, and the chemistry of plutonium reprocessing to be developed shortly in the Experimental Breeder Reactor No. 2. A fuel of better than 30,000 Mwd/ton average will be required to make AETR economic, under present rules; this is higher than anything achieved to date, except by oxide which is not suitable for the epithermal system.

Of the nuclear power industry at present, AI President Chauncey Starr says, "The industry is beginning for the first time to acquire the chief characteristic of an industry: having a product to offer for sale that is wanted."

General Atomic

This firm with its wheel-and-hub lab buildings in a university-campus setting, might well be nicknamed High Temperature Inc. For just about all the programs of General Atomic (a division of General Dynamics) are dedicated to achievement of greater efficiency by means of very high temperatures—and to development of materials to make possible the high temperatures. GA's principal reactor project even carries the name High Temperature Gas-cooled Reactor; it is to have a primary coolant outlet temperature of 1382° F; that of the Maritime Gas-cooled Reactor prototype will be 1300–1500° F. The thermionics group has in a sense to work backwards for the present toward a less efficient thermionic cell: it could now build a cell to work in a reactor with a fuel element operating at 3270° F—but no such element exists. And as for the fusion group—its useful operating range begins at 100,000,000°. The Orion project is classified, but any project using nu-

GENERAL ATOMIC'S $17-MILLION 'CAMPUS' DOESN'T STOP GROWING. Hub of wheel contains library and cafeteria, with 150 laboratories in wheel. To left of hub is administration building; L-shaped building below is experimental building and shops; smaller building below is fusion lab. Extending off to right are technical office buildings. Above hub, on canyon rim, are linear accelerator, HTGR and MGCR critical assemblies; further up toward right is Triga building (containing two Trigas, one a pulsing-type), and, finally, hot-cell building. Below latter in canyon (not seen) is control rod drive test facility

clear explosions for space propulsion is likely to use high temperatures.

GA invested $10 million in its John Jay Hopkins Lab for Pure and Applied Science—not counting what must be a huge payroll for its "brains stockpile"—without a product to sell. (Since then its Triga solid-homogeneous, zirconium hydride moderated research reactor has become the world's most popular, with 22 sold. And in three years the Hopkins Lab has grown to be a $17-million-plus plant.) Consequently the division is frankly playing for a big breakthrough. In HTGR it is trying to produce a reactor so much more efficient or economical that utilities will have no choice but to come to GA with their order-books, despite GA's lack of the usually-essential tradition of relations with the utility companies. HTGR itself has already attracted 53 utilities into the U. S.' biggest syndicate for construction of a reactor.

In one sense, HTGR is far ahead of its original plan, because the transitional first metal-clad (28-Mwe) core has been dropped in favor of going immediately to the ultimate, 40-Mwe graphite-clad core. This has been made possible because three sources—two in the U. S., one in Britain—say they can provide fairly impervious graphite. Based on its use, a fuel element has been designed that contains an annulus in which an auxiliary helium circuit sweeps out fission products directly into a hot trap. This system yet to be fully demonstrated; it holds promise of releasing from the fuel element but trapping inside the reactor vessel a large fraction of the fission products. This in turn of course means a less radioactive primary coolant circuit and longer fuel life, therefore greater economy of operation.

HTGR is already entering the hardware stage, with the pressure vessel, compressors, and the primary steam generators about to be ordered, and a new Fuels Development Building is being set up to make the fuel assemblies. GA hopes for a 30–36-month life for the first core, but is designing for 6–7-year life in the advanced version of HTGR which GA has started working on for ESUPRA.

GA is also moving into high gear on BORE (*see p. 31*).

Bechtel

One of the most aggressive engineer-constructors on the nuclear scene (some would delete "one of" in that phrase) is Bechtel Corp. The firm has already captured nine major nuclear jobs, six of which have reached the construction stage (one, Peach Bottom, is about to reach it shortly; another, Dresden, is already completed). Also in progress are Hallam, Big Rock Point, Humboldt Bay, and Canada's NPD reactor at Rolphton (the last being built by Canadian Bechtel). Perhaps even more remarkable is that the jobs in progress except Hallam are fixed-price turnkey contracts, on which Bechtel has contracted to take the loss if the job goes over budget; only Hallam, on which Bechtel is architect-engineer, is cost-plus-fixed-fee. Three other jobs not yet in construction include the Southern California Edison 360-Mwe reactor (*see p. 24*); the Industrial Reprocessing Group's chemical reprocessing plant project, now on dead center; and Spain's 30-Mwe power-and-test organic reactor, for which Bechtel did a preliminary design and cost estimate.

Rocket Engine Invitation Out

The joint AEC-NASA Nuclear Propulsion Office issued its long-awaited invitation for proposals—due April 3—on initial phase of a rocket engine development program. The job, Phase I of the role of an industrial engine contractor, is expected to run about 6 months and cost under $1-million, covering aid to Los Alamos in the Kiwi-B test program, preliminary design of a flight engine and study of an engine-development program. Phase II, when it comes, will carry the program to the hardware stage.

Aerojet-General Nucleonics

AGN, growing gratifyingly since its early days when it was primarily a purveyor of mass-produced 100-milliwatt training reactors, seems also to have changed its corporate personality since a new management team took over last April. AGN is now working in the field of compact nuclear power plants. It also is doing research-development in the field of advanced materials—for example, it is completing probably the world's first circulating rubidium loop, to operate at 1600° F with 100 lb of rubidium, under study as a coolant for compact reactors. Since its founding in October 1956 AGN's staff has grown from 100 to 600; the firm has just bought 474 acres adjoining its present 11 acres for future expansion.

Achievements include almost a year's satisfactory operation of GCRE (Gas Cooled Reactor Experiment) in Idaho, a stepping-stone toward the truck-mounted ML-1 (Mobile Low-power reactor No. 1), fabrication of which has just been completed. Its turbine-compressor is to be ready in midsummer, at which time the 330–500-kwe nitrogen-cooled, light-water-moderated highly mobile reactor will start operation as the world's first closed-cycle gas-cooled nuclear power plant. AGN has set up fuel development and production shops where it made the first two cores for GCRE and one for ML-1, and is now developing the third core for GCRE and second for ML-1. All are uranium oxide pellet-in-tube type. AGN also designed and fabricated an unusual semaphore-type control blade system for ML-1 which minimizes piercing of the shield by the control system.

AGN is building the mercury-vapor turbines for Atomics International's SNAP-2 (3-kwe) and SNAP-8 (30-kwe) vest-pocket space-power reactors. AGN is also halfway through a 15-month paper-study development job on SPUR—a 300-kwe scale-up of the SNAP reactors. AGN hopes "to go into a prototype reactor" after the paper study is completed.

New Instrument Firm Takes Unique Approach to Marketing

A new concept in radiation-equipment marketing has been embodied in a firm which went into business last month in Valley Stream, L. I.—Nuclear Industries, Inc. The firm has set for itself these goals: 1. to create a "family" of radiation-equipment manufacturers represented by a nation-wide sales organization offering an unprecedented variety of instruments; 2. to create its own wholly-owned subsidiaries for the distribution and servicing of primary and accessory instrumentation; and 3. to provide equity financing for new and established instrument companies trying to raise capital.

NI was already well along toward meeting these goals last month via arrangements with, or ownership of, eight firms—with negotiations proceeding for arrangements with, or creation of, several more companies. These firms, as a group, NI President and co-founder Jack Carlin believes, will "make up a marketing organization that none of the member companies could afford individually. Our interest is in putting together a family of companies complementary to each other, whose products together make up a formidable entity in the instrument industry."

NI "Family"

As of mid-February, the NI group included:

Radiation Equipment and Accessories Corp. (near NI in Lynbrook). REAC is a wholly-owned subsidiary headed by Edward Kerzner, president, and Jerry Weinstein, vice-president, both formerly of Baird-Atomic. Specializing in the physical and life sciences, REAC will stock and distribute instruments accessory to those offered by other firms in the "family," will manufacture or have manufactured primary and accessory instruments of its own design, and generally attempt to round out the instrumentation available through NI so a given customer can get most or all of his equipment from one source. Those instruments of REAC's own design, chiefly in the educational field, are expected to range from low-priced items to some as high as $60,000.

Atomium Corp., Cambridge, Mass. This less-than-two-year-old manufacturer of medical and other nuclear instrumentation has given NI exclusive right of sales representation for two instruments: a tape recording system for collecting medical data on magnetic tape (cardiac output, kidney function, etc.); and a low-background gamma detector capable of counting crystals of up to 8 in. dia. These were selected for NI representation, Atomium said, because "they are the kinds of things that go to customers" visited by NI salesmen. "If NI does a good job," an Atomium official commented, "I think it will be to our advantage to look to expanding [the sales agreement to other instrumentation]."

Cosmic Radiation Labs, Bellport, N. Y. In another sales agreement, NI will represent this five-year-old firm in the sale of transistorized detectors already available and other instruments, which Cosmic might design. "We will work with NI," a Cosmic official explained, "to come out with instruments that the scientists need and want—things that are not available from other manufacturers." Cosmic, with sales of $75–$100,000 in 1960, has never had a formal sales program.

Crystals div. of Isotopes, Inc., Westwood, N. J. NI's wholly-owned subsidiary, REAC, will be exclusive sales agent in the nuclear field for this firm's scintillation crystals (excluding New England). This business has been dominated historically by Harshaw Chemicals. As with Cosmic Radiation, the arrangement involves a product never given a significant sales "push" so Isotopes expects the NI sales organization to "increase our sales quite terrifically."

New England Nuclear Corp., Boston. This radiochemical company has also signed a sales agreement with NI, deciding against creating its own sales organization to see how the arrangement with NI works out. NENC President Edward Shapiro indicated he had been particularly influenced by NI's sales-incentive plan—to establish separate sales corporations in each of the eight cities where sales offices will be located and permit the salesmen there to hold as much as 20% of the stock in each of these corporations. NENC was represented by Baird-Atomic until earlier this year.

Oxford Engineering Corp., Wellesley Hills, Mass. Oxford is a young electronics firm which has not been in the radiation field. It has been manufacturing industrial counting equipment utilizing glow tubes and other electronic components employed in radiation instrumentation, however, and will enter the radiation-detection field through REAC. First item is to be a low-cost scaler for educational users, to be followed by other educational instruments. NI has taken an equity position in Oxford.

Reactor Experiments, San Francisco. In an arrangement similar to that with Oxford and the Crystals div. of Isotopes, Inc., REAC will be exclusive sales agent for the products of this 18-month-old firm. These include a neutron howitzer, activation foils and other equipment for education and research. There will also be an exchange of stock between Reactor Experiments and NI.

NI Organization

NI was founded by Jack Carlin and Richard O'Toole, president and secretary-treasurer, respectively, and both former officials at Baird-Atomic; the third NI officer is Louis Mead, vice-president for marketing and sales manager—and also formerly of B-A.

Sharp Leaves NI

One of the charter members of the Nuclear Industries "family"—Sharp Laboratories, La Jolla, Calif.—cancelled its agreement with NI and signed, instead, with Baird-Atomic on Feb. 10. Sharp, which had been represented earlier by B-A until its brief commitment with NI, manufactures low-background detection instruments. B-A has exclusive sales-representation rights for Sharp instruments in the U. S. and Canada; Sharp will also design instruments for marketing under B-A's name.

Nuclear Industries Management

Carlin

O'Toole

Mead

The three were the founders five years ago of Atomic Associates, which grew to a nationwide sales organization purchased by B-A two years ago, along with Atomic Accessories. When management differences arose last year, Carlin and O'Toole left B-A, subsequently forming NI.

Baird officials have made it clear they consider NI a competitor with the Atomic Associates and Atomic Accessories operations acquired in 1958. Carlin and O'Toole, in rebuttal, have pointed out that they left B-A for a reason typical in the management area—they were unable to agree with major policy decisions. In any event, B-A has not indicated whether it would take any legal action, commenting: "The matter has been referred to counsel for advice."

NI has begun to establish separate sales corporations in Boston, New York, Philadelphia, District of Columbia, Atlanta, Detroit, Chicago, Los Angeles and San Francisco—with plans to have salesmen in each city by the end of June. In addition, the company plans, through REAC, to represent its "family" of companies at appropriate trade shows.

Eventually, the equipment line available through the NI complex is expected to include process-control instrumentation, sophisticated instrumentation like liquid-scintillation counters and multi-channel analyzers, reactor instrumentation and a full line of radiation-detection equipment. The intention is to market transistorized equipment only.

Represent Hughes?

Meanwhile, NI was negotiating an agreement with Hughes which could turn out to be the broadest of any of the arrangements described above. Equipment involved: two new linear electron accelerators nearing the prototype stage at Hughes; a 2-Mev proton cyclotron for education and research; all of Hughes' solid-state detectors (NU, Feb. '60, 55); and, as developed, a line of radiation-detection instruments. REAC would be exclusive distributor of the solid-state detectors and NI would have exclusive sales representation on the other equipment.

The new Hughes accelerators are: 1. a "monopulse" linac of 10 Mev and 1 amp to be used primarily for simulation of nuclear explosions; and 2. a "compact" linac, also of 10-Mev energy, for medical therapy and radiography. The former would be priced under $100,000, the latter at about $125,000.

Hughes said it was also developing —on a later schedule—high-powered machines for sterilization, cross-linking, etc.

Decision on fate of ANP due—again

Once again fighting for its life, the Aircraft Nuclear Program is being reviewed in the Pentagon and a decision is due on completion of the review "within the next several weeks." Rep. Melvin Price (D-Ill.) was thus notified by the Defense Dept. last week after he had written to new Defense Secretary Robert McNamara urging a hands-off policy on the nuclear plane program as it is presently being conducted. Price told McNamara that responsibility for major technical decisions in the program should be left to AEC in consultation with the Air Force—thus excluding the Defense Dept.'s Office of Research and Development, headed by Herbert York. York's office is conducting the present review, however, and its decision will probably bear considerable weight on the program's future. Major issues are: whether to endorse the Eisenhower Administration's decision to drop one of the two reactors cycles now under development; if so, which one to abandon.

Packard, Tracerlab win suits against former employees

Two significant suits in the radiation-instrument field have been settled out of court—the settlements representing victories for established firms over employees who left these firms to set up competing companies.

Packard Instrument Co. Packard won a permanent injunction against Scott Nuclear Co. (NU, Dec '60, 34) on the manufacture of liquid-scintillation counters and other instruments similar to those manufactured by Packard. Effect of the settlement was to render Scott unable to function as planned until June 30.

Tracerlab, Inc. Tracerlab, after getting a temporary injunction against two former employees doing business as Electro Neutronics, Inc., Albany, Calif., won an out-of-court settlement under which the former employees: agreed to: 1. withdraw their low bid of $320,000 on radiation-detection instruments for nuclear submarines; 2. refrain from making these instruments and two others for 2½ years; pay Tracerlab's costs of the suit.

Remote-Camera View of SL-1 Core

FIRST CLEAR PHOTO looking down on top of SL-1 reactor after Jan. 3 accident (see p. 62, also NU, Feb. '61, 17). It was obtained by remote control using a motor-actuated movie camera suspended from a boom inserted into the reactor building, and shielded from gamma radiation by a lead lined box to avoid fogging of film. This photo is enlargement of one of 16mm frames. It shows 6 of 9 nozzles in vessel top head are open to atmosphere, but only one at top left (No. 8) is completely unobstructed. It's through this nozzle that AEC is trying to photograph vessel interior by lowering thin TV camera; problem is to shed enough light into vessel through partially-blocked nozzles without dislodging anything that might fall into reactor. On No. 8 nozzle, 2 studs (bottom and lower left) seem bent, rest seem stripped. Top center nozzle (No. 1): circular threading on top of control rod rack seems broken off, rack raised, as much as 6 in. Top right (No. 2): shield plug in place, no visible damage. Left center (No. 7): rack seems raised, as much as 6 in. Center nozzle (No. 9): circular pipe visible at left of hole (under broken control rod extension shaft lying across reactor top) may be sleeve of extension rod. If so, this implies central rod poison blade is sitting upright above core, its bottom edge on core top—and that it flew out of core at time of accident and fell back into present position. Right center (No. 3): rack is broken off, even with top of nozzle; impossible to say how far down rack break occurred. T-shaped wire just to lower right of nozzle is a sample holder for corrosion testing. Botton left (No. 6): shield plug in place, no visible damage. Shielding punchings lie scattered on it. Bottom center (No. 5): bell housing in place; no way of telling position of control rod inside it—may be all the way in or all the way out of core. No visible damage. Bottom right (No. 4): appears free of rack or other obstruction. This is over T-rod slot that contained dummy experimental control blade, which of smaller diameter than working blades and could have flown out through nozzle opening. Navy photo-interpreters have been sent to Idaho to help decipher this, other photos.

REACTOR NEWS

HRE-2 DOOMED; ORNL SEEKS GRACE

Oak Ridge is hoping for a reprieve for the Homogeneous Reactor Experiment No. 2, and ORNL director Alvin M. Weinberg has made a plea to AEC to reconsider its decision to close out the aqueous homogeneous reactor program by June 30. HRE-2 has been continuously at power since Dec. 15, including several times at 5-Mwe full power. No instabilities or evidence of uranium separation were found such as led to earlier troubles before design modifications were carried out (NU, Oct. '60, 28; Jan. '61, 25), and project leaders expressed satisfaction with the reactor's performance to date. Present plans are to continue running at least until May 1, although one shutdown is scheduled before then to insert some corrosion specimens into the core for study. Termination of the homogeneous program ("in favor," AEC said, "of increased development of the molten-salt concept") would write finis to one of the brightest dreams of the early days of nuclear power: the reactor system composed only of "a pot, a pipe and a pump."

TURRET TERMINATED TOO

Los Alamos' Turret reactor, an effort to pioneer unclad fuel elements in a high-temperature gas-cooled reactor, was dropped from AEC's 1961 construction plans late last year, it was learned last month. The $5-million project got the axe, AEC first said, "because of greatly increased construction costs"; this was promptly corrected —after Los Alamos said costs had not risen—to state that "unclad fuel performance and problems of radioactive circulating coolant gas can be investigated in existing reactors." About $450,000 has been spent to date on the project, Los Alamos said, over half for initial engineering studies. Title I design was nearly complete and construction was to begin this month. The special Turret team of 20 scientists and engineers will all be reassigned.

TO START BUILDING MGCR PROTOTYPE

AEC has finally announced construction of the Maritime Gas-Cooled Reactor land-based prototype, BORE (Beryllium Oxide Reactor Experiment), in Idaho. The long-awaited pilot plant for an advanced nuclear merchant ship reactor will be designed, built and tested by General Atomic division, General Dynamics, which has been developing the closed-cycle nuclear gas turbine concept since February 1958. Proposals from architect-engineering firms to AEC were due Feb. 20. Construction is to start this summer northeast of the Naval Reactors Facility in the National Reactor Testing Station. The high-temperature helium-cooled, BeO-moderated unit, fueled with a mixture of UO_2 and BeO, will have a first core 75 in. long and 24 in. dia, surrounded by a 7-in. thick BeO reflector. It will permit He outlet temperatures up to 1500° F at 1120 psia, and power levels up to 10 Mwth. MGCR has been under development as a 70-Mwth unit, so BORE's core volume has been reduced to ⅐th to maintain the same density; however the conceptual design of BORE includes provision for possible subsequent installation of a larger core within the same pressure vessel. Likewise it will be built at the outset without power conversion equipment, but a gas-turbine may be added later to demonstrate closed cycle operation. GA has been doing critical experiments on a honeycomb-type MGCR critical assembly at its labs near San Diego.

9 INTERESTED IN ORGANIC REACTOR

Nine public power utilities have expressed interest in AEC's proposed Improved Cycle Organic Cooled Reactor of 50 Mwe. They were: City of Burlington, Vt., plus 13 associated Vermont and New Hampshire public power groups; City of Hamilton, Ohio; Dairyland Power Cooperative, La Crosse, Wis.; Grand River Dam Authority, Vinita, Okla.; Mineral Country Power System, Hawthorne, Nev.; City of Greenville, Tex.; Choptank Electric Cooperative, Denton, Md.; Plains Electric Generation & Transmission Coop., Albuquerque, N. M.; Delta Electric Power Assn., Greenwood, Miss., with Southwest Miss. Electric Power Assn., Lorman, Miss., and allied groups. Burlington and Dairyland have been involved in previous atomic power projects (NU, Nov. '58, 24; April '59, 25; Feb. '60, 18). Meanwhile . . .

AI GETS ORGANIC DESIGN JOB

. . . Atomics International disclosed it had been authorized by AEC to proceed with conceptual design of the 50-Mwe advanced organic reactor, which is regarded as a prototype for a later 300-Mwe scale-up. The 50-Mwe unit is scheduled for 1964 start-up.

PRICES SET FOR REACTOR RESEARCH

The Western New York Nuclear Research Center, Buffalo, has set prices for use of its 1-Mwth pool reactor, to go critical in spring: $30,000/man-year for research by the center's own staff and use of lab space and equipment; $1,000/wk for use of the 12-in. beam tube, $500/wk for the smaller tube, or thermal column.

INDIAN POINT NEARS COMPLETION

Consolidated Edison's Indian Point nuclear station is 90% completed; pressure testing is under way using steam from an auxiliary conventional boiler. The turbine has been rolled, the superheaters tested and sealed. Criticality is scheduled in September.

NUCLEAR NAVY GROWTH QUICKENS

The accelerating tempo at which nuclear Navy projects are coming to fruition was never so apparent as in the last month, when the Navy's 16th A-sub, *Shark*, went to sea for the first time Jan. 22, only to be followed by the 17th sub, *Abraham Lincoln*, on Jan. 29. *Shark*, the third *Skipjack*-type attack sub, was commissioned Feb. 9. *Lincoln* completes the first class of five Polaris-firing sub, *Theodore Roosevelt*, fourth in the class, having been commissioned Feb. 13. *George Washington*, first Polaris sub, returned from her first patrol after setting a new 67-day submergence record (beating Seawolf's 60-day mark set in fall of 1958); she was relieved on station by her sistership *Patrick Henry*. (Third of the class, *Robert E. Lee*, is running shakedown cruises and will soon begin regular duty.) Meanwhile the second of the improved *Ethan Allen* class of Polaris subs, *Sam Houston*, was launched Feb. 2; and the keels of two more, *Lafayette* and the still-unnamed SSBN 620, were laid. Among the nuclear surface ships, seven reactors aboard the carrier *Enterprise* were being prepared for criticality (one is already critical); one of the cruiser *Long Beach's* two reactors was expected to start up early this month, and the frigate *Bainbridge* is to be launched in April.

In Washington, the Eisenhower administration's fiscal '62 budget called for thirteen more naval reactors—five Polaris and three attack subs would be fully funded, while long-lead-time component procurement for five more Polaris subs would be authorized. And President Kennedy told Congress he had directed action to use unobligated shipbuilding funds to order immediate starts on the [seven] Polaris subs authorized only for advance procurement in fiscal '61.

WORLD NEWS

Euratom's Organic Program Advancing

Euratom has asked for a proposal to design an experimental organic-moderated heavy water cooled reactor of 40 Mwe, 150 Mwth, called ESSOR—pilot plant in the $6-million, Euratom-wide ORGEL project to develop the organic reactor concept. Two German firms—Siemens and Interatom—in cooperation with Indatom in France, Belgonucléaire in Belgium, Neratom in Holland, and others—are preparing the proposal, to be submitted by April 30. Likeliest location for ESSOR (French: ESSai ORganique, or "organic trial" reactor) if it is built would be Ispra, Euratom's main nuclear lab. Euratom had earlier signed 12 research contracts on ORGEL work—seven in France, four in Italy, one in Belgium. The two most recent in France call for work at Grenoble, using the Mélusine pool reactor, to determine the best organic coolant; and study of heat transfer in organic reactors.

France, Euratom to Build Gas-Cooled Unit

France and Euratom will collaborate on an experimental gas-cooled reactor to be built at the Commissariat à l'Energie Atomique's new reactor testing station at Cadarache. The advanced reactor would be fueled with enriched uranium. It would be about 30 Mwth in power level, with gas exit temperatures on the order of 930–1110° F. Construction would presumably start some time next year; and agreement covering the joint project is expected to be signed soon.

U. S. U-235 for French Sub's Critical

The U. S. has delivered 44 lb/enriched uranium to France for the critical experiments on France's first nuclear submarine. The 90%-enriched U-Al alloy plates clad in Al are for use in a critical assembly at Saclay for the land-based prototype reactor to be started this year at Cadarache. France is undertaking to design her own nuclear submarine propulsion plant—just as she achieved independent development of the gaseous diffusion process and of nuclear weapons without help.

Germans Let Design Contract on A-Ship

A design and development contract for Germany's organic ship reactor was signed in Hamburg by Euratom, GKSS (Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt = Society for Nuclear Energy Utilization in Shipbuilding and Navigation), and Interatom—the jointly-owned subsidiary of Atomics International and Demag, German heavy machinery manufacturer. Under the contract, Euratom will finance 40%—$1.06-million—of the $2.7-million design and development costs for a 10,000-shp OMR. Preliminary design had begun early in 1959; final blueprints are now to be completed by end of 1961. Although German shipyards faced a Jan. 31, 1961, deadline to submit proposals on building the ship, decision on construction of the vessel (probably a 22,000-ton tanker, costing about $8.3-million and taking 2½ years to build) will be made early in 1962. It's hoped Euratom will contribute also to its construction cost. This is the first time Euratom is participating in an all-German project; however it plans also to promote nuclear ship projects in France (gas-cooled), Italy and the Netherlands (both pressurized water).

Tri-Nation Zirconium Firm Formed

Zirconium has lured Montecatini, Pechiney and Degussa into partnership. The Italian, French and German firms—three of the biggest names in European metals and chemical production and all three deeply involved in atomic energy—have set up a joint subsidiary with equal participation, to produce zirconium sponge and ingots, and to do research on new applications for the metal in the chemical as well as the nuclear industry. The new company, Société Industrielle du Zirconium, will have headquarters at 195 rue du Faubourg Saint-Honoré, Paris 8. Sale of its products will be handled both by a sales organization of its own, and by those of the participating companies.

Francesco Giordani Dies

One of the founders of Italy's atomic energy program and of Euratom, Francesco Giordani died after a long illness in his native Naples, aged 64. A professor of chemistry at the Univ. of Naples, he was long president of CNRN, the National Committee for Nuclear Research. In 1956 he headed the Italian team that negotiated the U. S.-Italian research bilateral. He helped lay the groundwork for establishment of Euratom, and was—with France's Louis Armand and Germany's Franz Etzel—one of the "Three Wise Men of Euratom."

22nd Triga to Mainz Univ.

Prof. Fritz Strassman, co-discoverer with Otto Hahn of nuclear fission in 1939, will get a Triga reactor for his Institute for Inorganic and Nuclear Chemistry at the Univ. of Mainz. The Bonn government has made available $367,000 toward purchase of the reactor, to be financed jointly by the Federal government and the state of Rhineland-Palatinate. The 30-kwth Mark-II (above ground) Triga constitutes the 22nd Triga sale, giving General Atomic, its builder, a clear U. S.—and world—lead in research reactor sales competition.

Japan Nears Decision on 2d Power Unit

Japan Atomic Power Co. is close to a final decision on plans for installation of its second large-scale power reactor, to follow the 150-Mwe Calder-type gas-cooled unit now under construction at Tokai. Nine power utility firms—stockholders in JAPCO—fought all last year to have their own reactors for their separate grids, but finally gave up and agreed to give the second reactor to JAPCO. There was also a struggle between two of the biggest among the nine—Tokyo Power Co. and Kansai Power Co.—to have the reactor located respectively at Kawasaki near Tokyo, or in the Osaka area. A gentleman's agreement was reached late last year to have it installed on the Inland Sea coast near Himeji, about 20 mi southwest of Kobe (in turn only 25 mi west of Osaka. Once JAPCO's decision is sealed, an all-out sales competition can be expected between the Westinghouse-Mitsubishi group and General Electric, tied up with both the NAIG (Mitsui-Toshiba) and the TAIC (Hitachi) groups (NU, May '58, 24; Jan. '59, 19). JAPCO plans to send a mission to the U. S. this summer—which presumably will visit both Dresden and Yankee—before it makes a final decision on reactor type.

IAEA Governors Approve Safeguards

At its Jan.–Feb. meeting, the International Atomic Energy Agency's Board of Governors approved the safeguards principles and procedures against diversion of Agency assistance to military purposes—over strong objections by the Eastern bloc and India. The General Conference last fall had approved the plan in provisional form, 43-19. The Board also approved IAEA participation with Norway in a joint reactor-physics research program in Norway's new zero-power reactor, NORA. In a trilateral (IAEA-Norway-U. S.) contract, the U. S. will lend the 3%-enriched core it used in critical experiments for NS *Savannah*, while Norway will provide a natural and a 1.7%-enriched core.

NEWS IN BRIEF

ORNL Studying Non-Nuclear Projects

A series of seminars on advanced technologies outside the nuclear field is being conducted at Oak Ridge National Laboratory as ORNL moves to consider what other research-development projects it might eventually adopt. Alvin M. Weinberg, ORNL's director, commenting on the seminars in his annual "state of the Laboratory" speech, had said: "Oak Ridge might consider areas of endeavors outside the atomic energy field." But he also stressed ORNL's fundamental role is the development of a truly long-term solution to mankind's energy problem, and added that: "Although I am very interested in seeing where the advanced technologies seminars lead, I cannot really believe that for many years ORNL must look beyond nuclear energy."

Weinberg explained that the Advanced Technologies Seminar was organized in order to form an opinion as to whether such outside projects would make sense as work for the Lab. He said: "In these seminars a variety of possible additional missions—some quite outside nuclear energy—are being discussed. For an advanced technological problem to be uniquely suited for further exploitation by us, I would say it must be big, expensive, strongly in the national interest, and must not be ready for commercial exploitation." Among such missions, Weinberg mentioned desalting of sea water, weather science, oceanography, space technology, chemical contamination of the biosphere, and large-scale biology.

"Our job as a National Laboratory," he declared, "must be to do those things which are needed to put sense into our country's atomic energy program. If this means gambling on very big projects on whose success the future of large parts of the institution depends, we must be ready to take such gambles." He explained: "The central job of nuclear energy—the development of a long-range energy source, complete with waste disposal and chemical recycle, which will be available when we really need nuclear energy"—this prime task "is not being attacked with full vigor and seriousness." Explaining further, Weinberg said: "If our course in applied research consists primarily of doing big, complete projects, we must be able to identify a succession of big projects which are in the national interest and which the Laboratory is ready and willing to do. In nuclear energy, because of heavy pressure from private or quasi-private institutions, the projects which are open to the Laboratory tend to be circumscribed. Many suggestions have therefore been made that the atomic energy laboratories should begin to look at projects in other areas of technology which are in the national interest."

NCRP to Remain a Private Body

The National Committee on Radiation Protection, which has initial basic responsibilities for recommending radiation exposure levels in the U. S., has resolved to turn down several invitations to join other private groups. It will remain an independent scientific organization. This resolution for the 31-year-old group was reached, according to NCRP officials, after a study of the related problems of affiliation. Recently, there was discussion about NCRP's joining the proposed Institute on Radiation (NU, Feb. '61, 27). Now, NCRP, in order to clarify its status as a private group —it has 150 of the nation's pre-eminent physical and radiation health scientists as members—will draft and formalize a constitution and by-laws, and, in order to retain its autonomy objectives, will seek public and private financial assistance grants as a non-profit organization.

Little Support for Federal Nuclear Power

Despite a report in January of the Kennedy–Johnson Natural Resources Advisory Committee recommending vast federally–produced low–cost nuclear power, no support for the idea has been shown by government leaders. This was indicated by an informal survey by NUCLEONICS of officials in a position to implement the report's recommendations in both the executive and legislative branches of government. Said one House member, a leader in defining House Interior and nuclear affairs: "The development of nuclear power continues to be a straight research–development job. The question of public–vs–private nuclear power, despite its fires being fanned by the last Administration, is a non–sequitur, and the only way to stop being such, in point of time, is for federal and private funds to develop competitive power from the atom. This will take some time. The Kennedy–Johnson advisory report was interesting, but I cannot consider it as the guideline for atomic power."

Rep. Frank R. Smith (D–Miss.) directed the report's preparation following recommendations made by the committee's 200 members who represented regions throughout the U. S. Besides urging the Kennedy Administration to provide a vigorous conservation and energy resources development program, the report recommended an increased nuclear and solar energy program for all regions. It urged the government, moreover, to assert primary responsibility for supplying nuclear energy: "Atomic power developed and financed by the people should be made available from federal nuclear power as soon as production costs can be materially reduced."

AEC Denies Halt in Equipment Grants

AEC has denied industry rumors of a halt in some equipment grants to educational institutions. AEC had stopped training–reactor grants last August, but, in recent months, rumors have been spreading that other types of equipment were being dropped from the grant program. AEC officials, who said they have been getting queries as a result of the rumors, declared: "The only thing excluded from the grant program is the teaching reactor—everything else is still in." Noteworthy are the amounts AEC has committed for grants: more than $1 million of its current $3.1 million grants budget in a round of grants announced last November; a second round is to be made in April. About $3.5-million has been requested in the '62 budget for grants in the fiscal year beginning July 1.

Rep. Morris Joins JCAE; Hearings Scheduled

Rep. Thomas G. Morris (D-N. M.) joined the Joint Committee on Atomic Energy last month as the successor to former Rep. Carl Durham (D-N. C.). Rep. Chet Holifield (D-Calif.) took over the chairmanship from Sen. Clinton P. Anderson (D-N. M.). Morris is a 41-year-old civil engineer and rancher who is beginning his second term in Congress. Under Holifield's chairmanship, JCAE has slated hearings on the state-of-the-atom (began Feb. 21), the nuclear-rocket program (closed hearings in March), radioisotopes in agriculture, biology and medicine (March or April), and the nuclear regulatory situation (probably in April).

RADIATION NEWS

Civilian Food Irradiation Program Gets New Manager

Management of AEC's civilian food–irradiation program was taken over last month by Kevin G. Shea, a senior scientist from Curtiss-Wright Corp., and a veteran of five years in the food–irradiation field. The program is conducted by AEC's Office of Isotope Development. As a food technologist, Shea spent three years in the military food–irradiation program as executive secretary of the Interdepartmental Committee on Radiation Preservation of Food; he joined C–W two years ago when C–W received the Army Quartermaster Corps' contract to design a large cobalt–60 irradiator. Shea was also a consultant to the Organization for European Economic Cooperation—from late 1959 to early 1960—on establishment of a low–dose food–irradiation program in Western Europe.

The new manager was brought into the civilian program, one AEC official explained, because "we felt we wanted to get a senior person with substantial experience in both food technology and radiation–processing of food—whose job would be solely management of the food programs." Shea will also manage AEC's part in the Army's food–irradiation program: mainly, the design, construction, and testing operation of a new research facility to be built at Natick, Mass. Natick will have both a 1–million–curie cobalt–60 irradiator and a 24–Mev, 18–kw electronic linear accelerator for food–irradiation research.

Meanwhile, Brookhaven National Laboratory has gone out for industrial bids on the second research facility in the civilian food-irradiation program—a Chinese copy of the 30,000-curie, cobalt irradiator to be installed at Mass. Institute of Technology early this year. The second irradiator will go to a university on the West Coast for low-dose studies on fruits and vegetables. Brookhaven hopes this irradiator will be completed by June 30.

Tracerlab Charges 2 Former Employees with Pirating

In a suit in Federal District Court, San Francisco, Tracerlab, Inc., charged two former employees with pirating secret company information which, allegedly, enabled them to underbid Tracerlab on a $347,000 Navy contract for radiation-monitoring devices for use on nuclear submarines (plus spare parts).

Tracerlab maintains that the guiding factor in such a case is not the existence of a patent, but whether the item in question is unique and whether it was developed exclusively through the efforts of its declared owner. Tracerlab said that the two employees involved held the titles: business manager/temporary contract manager and supervisor of contracts and systems engineering. The former official became president, the latter, vice-president, of the Electro Neutronics, Inc., Albany, Calif. They left Tracerlab's Richmond, Calif., division in 1960. Subsequently, EN won a Navy contract for 43 radiation monitors with a possible 15 additional units to be ordered. Tracerlab alleges that the design for these was stolen, along with sufficient pricing information to enable EN to underbid Tracerlab for the job. Tracerlab, claiming $100,000 damages, received from the court a temporary restraining order, late in January, against fulfillment of the contract by EN.

Tracerlab maintained further, in its suit, that although the work was done under Navy contract, the Navy's only function was to supply performance specifications, from which Tracerlab worked almost two years to develop the detection device. Several devices were subsequently sold by Tracerlab to the Navy. "Also," reads the complaint, "the cost analyses and estimates . . . were the result of continued tabulation, study, and correction of costs and methods during the period of experimentation, trial and error, and development."

A spokesman for EN told NUCLEONICS that its defense was based on the fact that the devices in question would not have been developed without the presence of a government contract, and that, consequently, the so-called "secrets" must be considered to be in the public domain. Further, EN claims that because the government allows a fixed and limited profit margin, and because the amounts of contracts are public knowledge, it is relatively simple to work out a basic pricing formula without access to secret company information. A settlement of the case out of court has been predicted by informed sources.

Euclid Studies Radiation-process-control Field

Euclid Electric Mfg. Co. started a 6–month survey and evaluation study in January to determine whether it could, economically, enter the radiation-process-control field. Heading this study for possible diversification, as new director of advanced research for the Madison, Ohio, firm, is Clive Yeomans, a veteran of 12 years in radiation technology—he was formerly with Martin Co., Lewis Research Laboratory of the National Aeronautics and Space agency, and Victoreen Instrument Co. The study will show if Euclid's existing production facilities can be utilized to manufacture the new line of radioisotopic control devices as well as its traditional heavy industrial equipment: prime movers and heavy–duty electrical engines. Devices to be covered by the study include those which use cobalt–60, cesium–137 and iridium–192. Euclid's license application for research with these sources, as well as neutrons for possible neutron gages for moisture detection, has been filed with AEC. Other objectives of Euclid's study include: 1. determine use of and market for radiation devices among its traditional customers; 2. determine whether its salesmen can handle, without extensive retraining, the new production line. A decision is expected this summer.

3–M Makes First Big Sale of Radionuclides

Minnesota Mining & Manufacturing Co. recently became a supplier of nuclide sources, with its first large sale to a radiation–gage manufacturer of beta–emitting materials. The firm's microspheres, which 3–M claims to be chemically inert and harmless (except for radiation) in case of accidental ingestion, are ceramic–coated in three steps: 1. the isotope is sealed within the ceramic microspheres, or "beads"; 2. these are sealed in stainless steel or another metal; and 3. they are coated again with ceramic. Except when required for medical experimentation such as cancer therapy, where short lived isotopes are sold in bead form, 3–M will sell only complete sources.

U. S. Nuclear Corp. Buys Isotope Specialties Div.

Isotope Specialties, a Burbank, Calif. division of Nuclear Corp. of America, has been purchased by U. S. Nuclear Corp., also of Burbank. Isotope Specialties, a producer of labelled compounds and an active consultant in radiation matters, will retain its identity, but as a division of its new owner. Alden Tschaeche, formerly West Coast manager of Landauer, Jr., & Co., a film badge firm, will be general manager. By this acquisition, U. S. Nuclear complements its activities in radiochemicals, health-physics, servicing, detection instruments, tracers, and radiation handling and shield equipment.

NOW AVAILABLE, TRANSISTORIZED SINGLE CHANNEL ANALYZER SYSTEMS WITH ELECTRONIC SWEEP

In these completely transistorized systems, the "window" electronically sweeps across the energy spectrum for 10, 20 or 30 minute periods without the use of motors or mechanical linkages. Because of modular construction a wide variety of combinations can be assembled. Modules available include single channel analyzers with or without electronic sweep; linear, logarithmic and linear-logarithmic ratemeters; scalers with preset and/or elapsed timers. The analyzer/amplifier is capable of driving any ratemeter module as a recording spectrometer, or a scaler may be substituted for differential counting. A complete line of scintillation detectors is also available for use with these systems. RCL Recording Spectrometer, Model 20508. (illustrated below) consists of: Analyzer/Amplifier with Electronic Sweep times of 10, 20 and 30 minutes • Linear Ratemeter—up to 10^6 counts per minute • Detector High Voltage Supply— ± (500 to 3000 v.) • Strip Chart Recorder—1 ma. galvanometer type • Four Module Cabinet—19¼" wide x 12" high x 17½" deep.

For a copy of RCL's new Catalog 18, write

RCL

RADIATION COUNTER LABORATORIES, INC.

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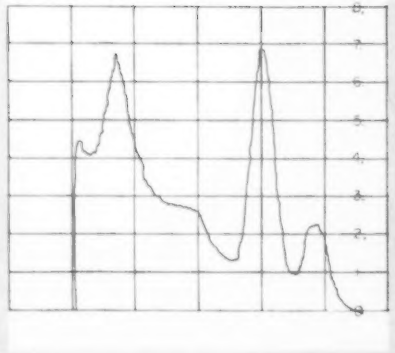
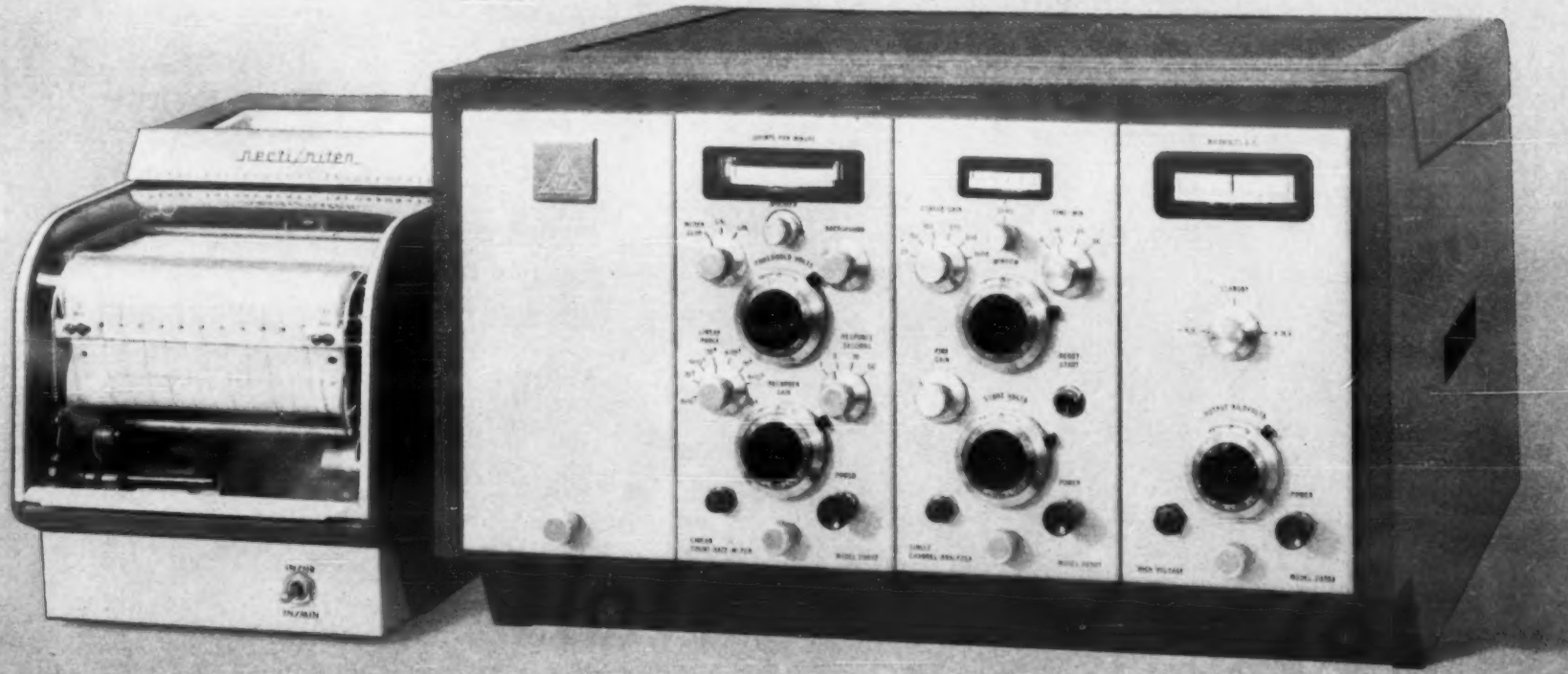


Spectrum from RCL Recording Spectrometer System, Model 20508



Today nuclear engineers must function simultaneously and successfully in two time zones . . . in the Now of Practicality and the Tomorrow of Possibility. Through the development of atomic power, Stone & Webster has served as a bridge between these often apparently conflicting objectives At Yankee Atomic, Stone & Webster engineers applied their skill and experience to the task of tailoring the most advanced theories to present commercial expectations While future design may prove more economical, the Yankee Atomic Electric Company project has more than exceeded original expectations Stone & Webster constructed this nuclear power plant at Rowe, Massachusetts, and designed it in collaboration with Westinghouse Electric Corporation Currently, we are acting as Agent for the design and supervision of construction of a nuclear plant for Carolinas Virginia Nuclear Power Associates, Inc. to be completed in 1962 With our subsidiary, Associated Nucleonics, Inc., we are prepared to undertake complete design and construction of nuclear power plants here and abroad.

OF time AND THE atom

STONE & WEBSTER ENGINEERING CORPORATION

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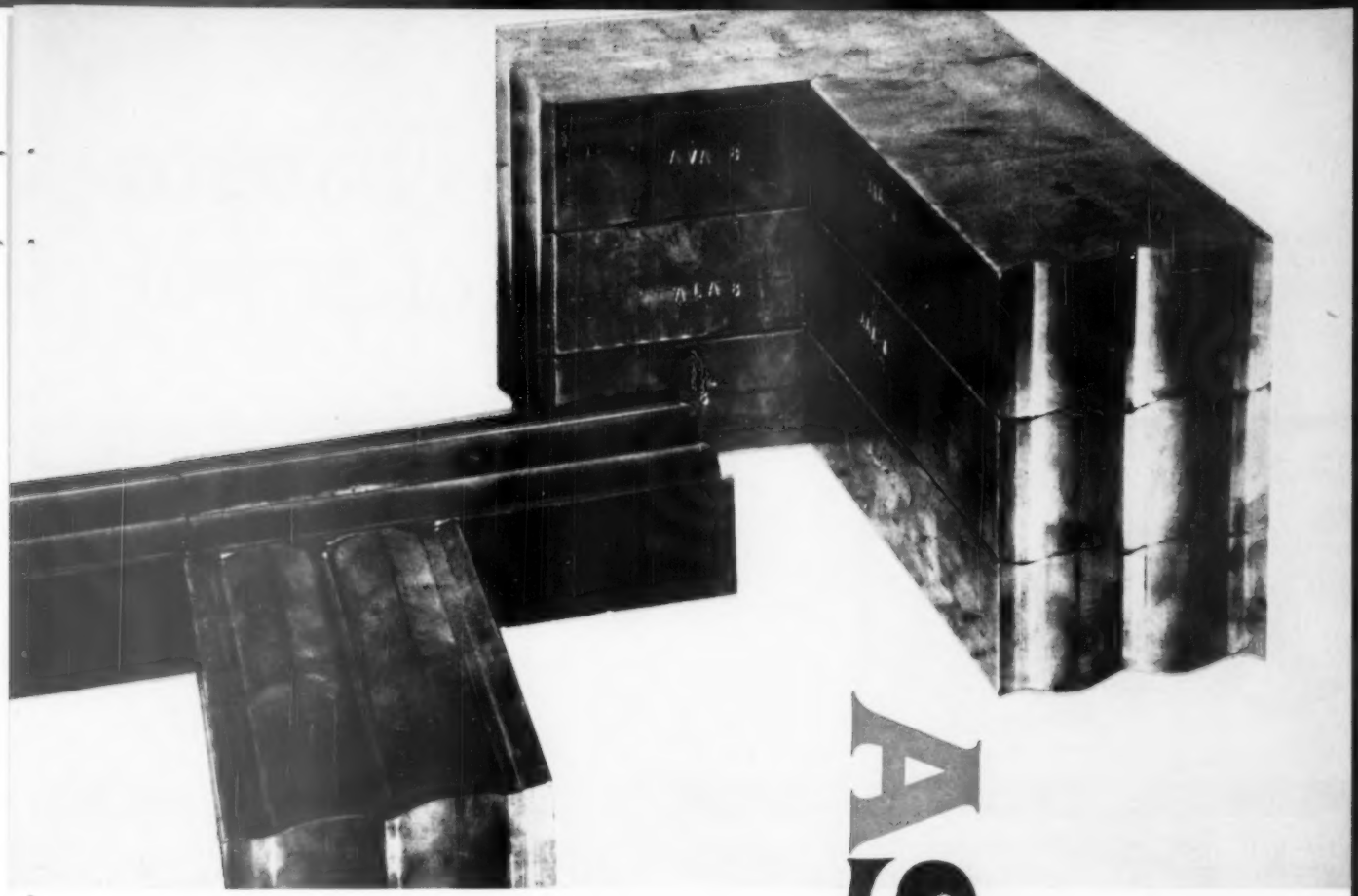

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*Patent No. 2,970,218

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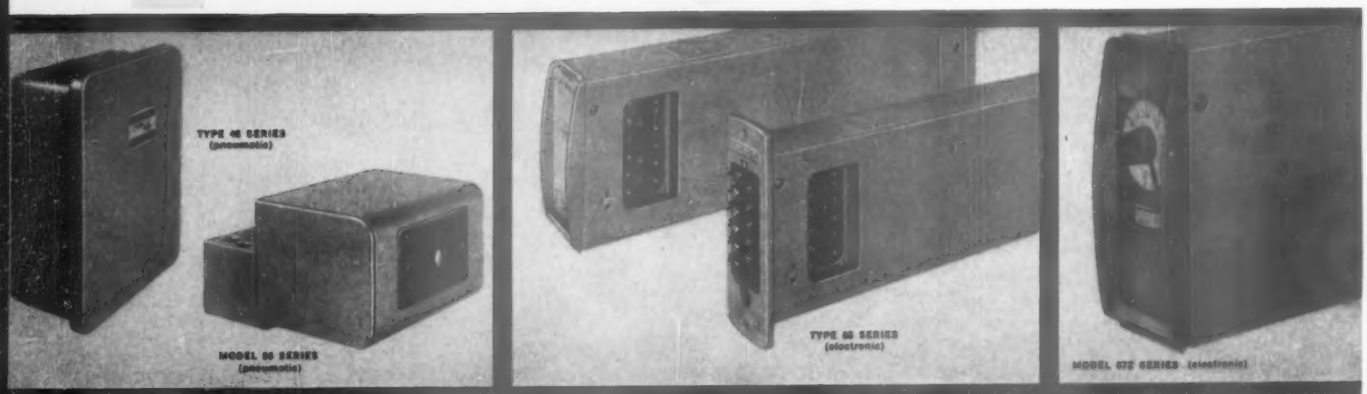
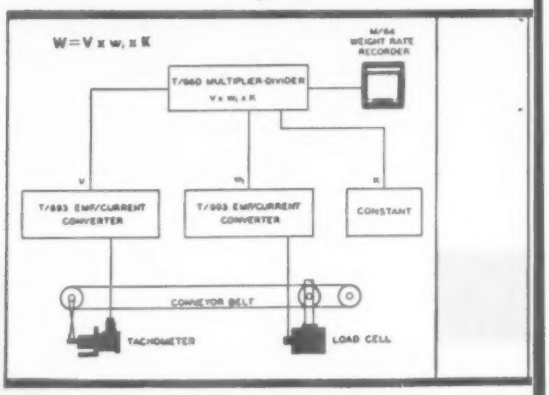
new low-cost Foxboro automation of power



FOXBORO ANALOG COMPUTING STATIONS

▶ TYPICAL



WEIGHT RATE COMPUTATION

Gives operator continuous recording of actual weight of solid fuels being conveyed by belt. For example, T/66D Multiplier-Divider calculates actual weight-rate from load cell and belt speed measurements.

Analog Systems simplify plant computations

both pneumatic and electronic units available

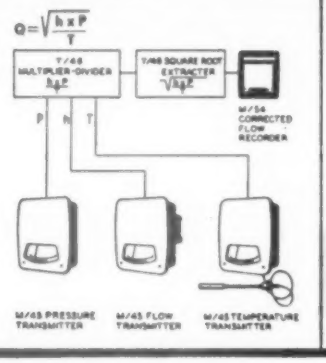
Analog computing systems have been known and used for years. Yet their potential for increasing plant efficiency has hardly been scratched.

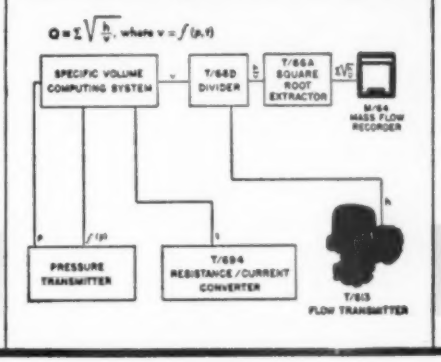
Just look what they can do! Continuous calculation of all the arithmetic functions: addition, subtraction, multiplication, division, square root extraction — in any combination. And all done automatically by a single packaged system.

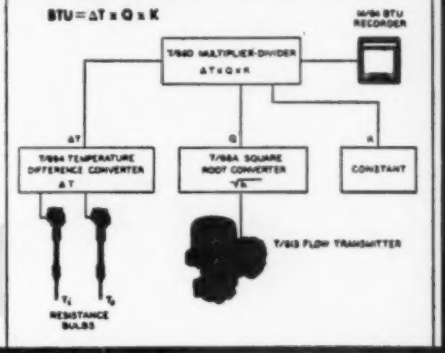
And look how it simplifies the operator's job. Instantaneous calculation . . . with records to prove it. No slide rules, no interpolation, no planimeters — and most important — no mistakes.

Because Foxboro Analog Computer Systems are relatively low-cost ($2500-5000 average) you can "spot" them about your plant for maximum efficiency. Or, they can be grouped together at a central location to solve more complicated equations. Pneumatic and electronic systems available.

CALCULATIONS MADE WITH FOXBORO ANALOG COMPUTING SYSTEMS







GAS FLOW COMPUTATION

In common use to compensate gas flow readings — air and fuel — for changes in line temperature and/or static pressure. In the pneumatic system shown here, the Foxboro T/46 Multiplier-Divider and the Square Root Extractor allow operator to read corrected flow directly.

MASS STEAM FLOW COMPUTATION

Calculates weight-rate of superheated steam flow, through a specific volume computing system individually designed for each application. Pressure, temperature, and flow measurements are combined so operator can read mass steam flow directly on a M/64 Recorder.

BTU COMPUTATION

Determines actual amount of heat being transfered to or from a heat exchanger. Electronic system shown uses a Foxboro T/66D Multiplier-Divider to produce a signal equal to product of flow and temperature difference. Operator reads directly in Btu's.

WHAT CALCULATIONS WOULD YOU LIKE TO AUTOMATE? ➔

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ONE SANDUSKY CENTRIFUGAL CASTING ...makes 4 giant stator shells

Specified by Westinghouse for 4 canned motor pumps soon to be integral parts of reactor system in Yankee Atomic Electric Plant in Rowe, Massachusetts

One king-size 17-ton Sandusky casting supplied the main motor bodies (stator shells) for the four pumps being built by Westinghouse, each to handle 23,600 g.p.m. of pressurized water through the reactor core.

The 25-foot-long Sandusky casting was centrifugally spun of a modified CF-8 (Type 304 L) stainless steel, then machined by Sandusky to a 3" wall thickness, 31½" on the O.D. This huge casting was hydrostatically tested to 3800 psi before being sectioned into four 68" lengths.

These stator shells represent another *new and exacting application* for Sandusky Centrifugal Castings—which may offer a practical and economical answer to *your* cylindrical requirements also. They are available in diameters from 7" to 54"—in lengths up to 33 feet—in heat- and corrosion-resistant stainless, carbon and low-alloy steels and a wide range of copper-base and nickel-base alloys.

Let us show you how Sandusky Centrifugal Castings can help solve your cylindrical problems. Write to us at Sandusky, Ohio.

SANDUSKY CENTRIFUGAL CASTINGS

SANDUSKY FOUNDRY & MACHINE CO.

SANDUSKY, OHIO Stainless, Carbon, Low-Alloy Steels – Full Range Copper-Base, Nickel-Base Alloys

Now INDICATION-FREE tubing

an extra value in Superior nuclear-quality stainless heat exchanger tubing

You can now specify *indication-free* Superior nuclear-quality stainless steel heat exchanger tubing. When you do, you get tubing that has been subjected to the specified red or fluorescent dye penetrant inspection procedure. All indications have been explored and removed within the minimum allowable wall thickness. The resultant product is considered to be *indication-free.* This eliminates surface defects that may lead to stress corrosion cracking, leaks and fractures when the tubing is bent.

Specification STC 104 gives the quality and technical requirements of Superior nuclear-quality heat exchanger tubing in austenitic stainless steels, including Types 304, 304L, 316, 347 and 348. Write for your copy. Nuclear heat exchanger tubing is available in other materials, too. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

Some Typical Specifications for Superior Nuclear Quality Heat Exchanger Tubing

• CONDITION	Solution annealed, bright finish. Other tempers and finishes can be supplied.
• RAW STOCK QUALITY	Selected raw material with conditioned OD and ID. Tested for wall variations and concentricity before processing.
• FINISH QUALITY	Commercial tolerances shall be held unless otherwise specified. Ovality shall be held within 3% of the theoretical average OD. Commercial straightness shall apply. Dimensional checks shall be made on a 100% basis. OD shall be 100% visually inspected.
• CLEANLINESS	Both inside and outside surfaces shall be bright and free from discoloration and carburization, grease, dirt, metal particles, and other foreign matter.
• FLARING AND FLATTENING	Two samples from each lot shall be flared and flattened.
• HYDROSTATIC TESTING	All tubing shall be hydrostatically tested to working pressures.

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The big name in small tubing

NORRISTOWN, PA.

All analyses .010 in. to ⅜ in. OD—certain analyses in light walls up to 2½ in. OD

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Here's one of the few areas in America where it is possible to attract personnel in every category without difficulty.

Why? — No executive or employee need be more than 15 minutes away from home and garden, from fresh and salt water, fishing, bathing, boating, water skiing . . . no more than 15 minutes away from schools, churches, shopping centers, recreational and social activities.

All this, plus a favorable business climate . . . and SUN-sational living all year, in this enchanting land of flora and fauna.

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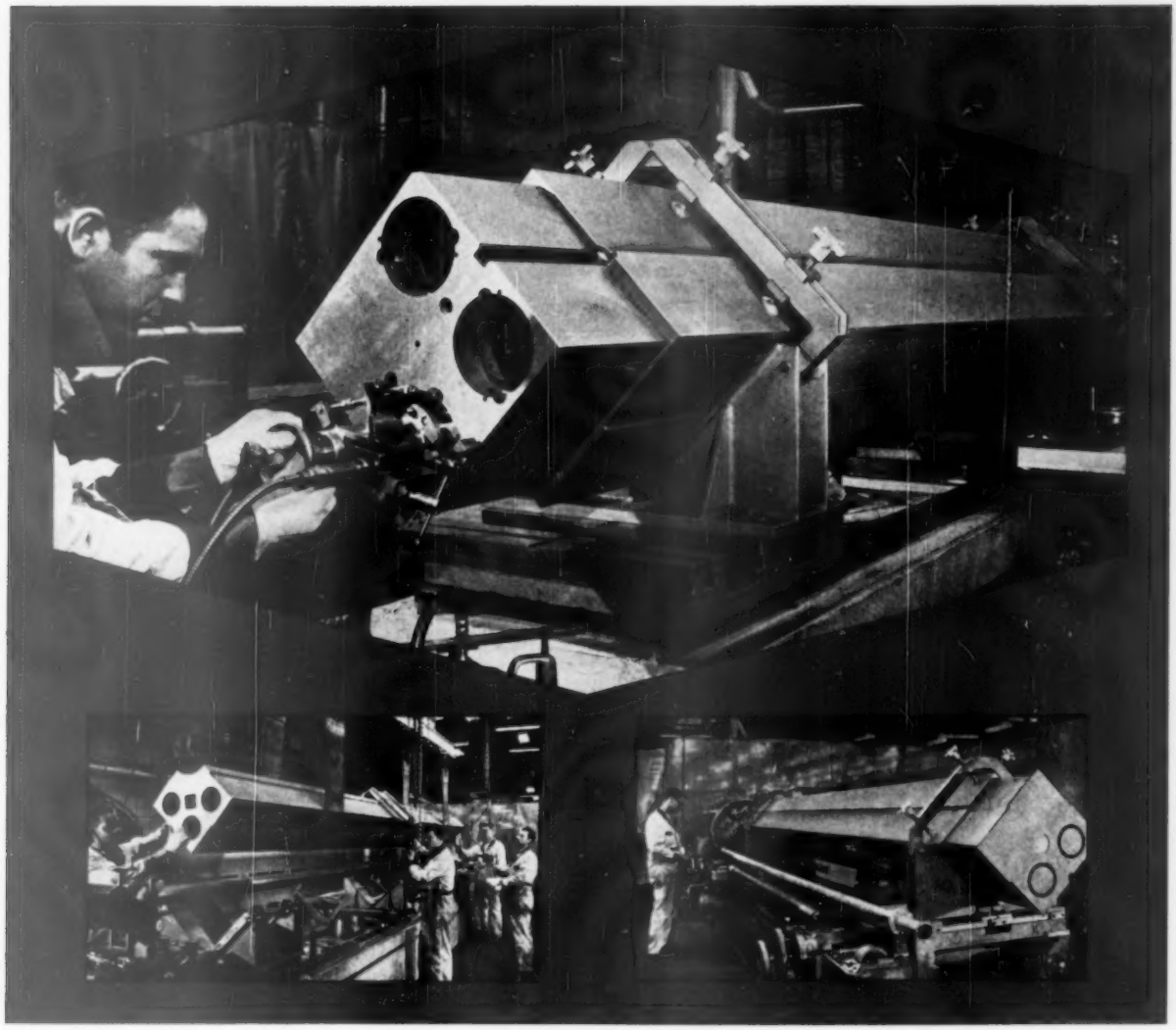

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The largest nuclear graphite ever produced is shown in process of machining at a National Carbon Plant. Each piece is 16.3" square by approximately 20' long. Width, thickness, and hole diameter tolerances are ±0.005". The 5.125" diameter holes are bored through the full length.

This is another example of the production and machining facilities that National Carbon makes available to the nuclear industry. Whatever your needs, have National Carbon do the job . . . whether it's simple reactor blocks, fuel element concepts, low permeability graphite, molds or crucibles, complex reactor parts or intricate nuclear metal processing assemblies. For information, contact National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, New York. In Canada: Union Carbide Canada Limited, Toronto.

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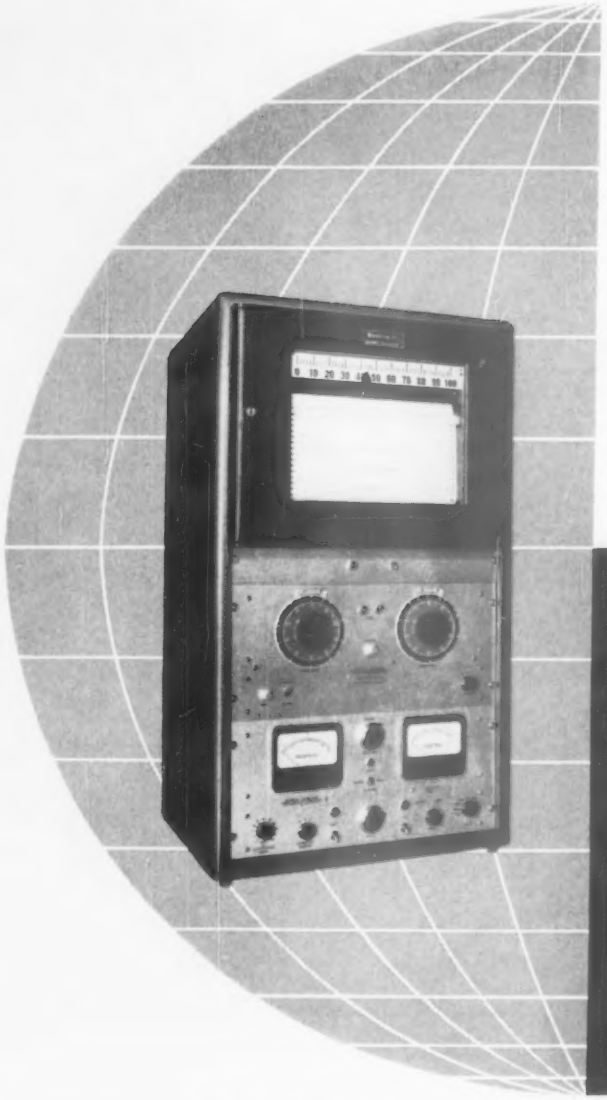

RAPID RADIATION ANALYSIS

with RIDL Model 50-1

AUTOMATIC SCINTILLATION SPECTROMETER

...scans whole or any part of spectrum

...automatically prints out data and resets

How much stability can one expect in an instrument? Surprisingly, a great deal . . . as found in the RIDL Model 50-1 Automatic Scintillation Spectrometer. This fine spectrometer is just as useful today as it was when first introduced. Actually sales have increased each year. This obviously indicates good basic design, the utmost in reliability and wide versatility.

The Model 50-1 is a completely automatic integral and differential **single-channel pulse height analyzer.** It is used for identification of isotopes, for gross counting studies, comparative measurements, luminescence studies and half-life determinations. It is ideal for use with automatic sample changers, resetting with each new sample. Due to the use of an **electronic sweep,** there is no mirror effect.

For beta and gamma spectroscopy or spectrometry, the Model 50-1 offers small laboratories an instrument adaptable to a variety of detectors and experiments. Its separate components find multiple uses in large laboratories. It provides a choice of full-scale ranges and time constants, various scanning speeds, and a stable HV supply. **The two-second Brown recorder** included in the system provides various chart lengths.

For a quality line of beta, gamma and X-ray spectrometers consult the RIDL General Catalog 61. For all detection and measuring instruments used in the radiation field, write today to Department K.

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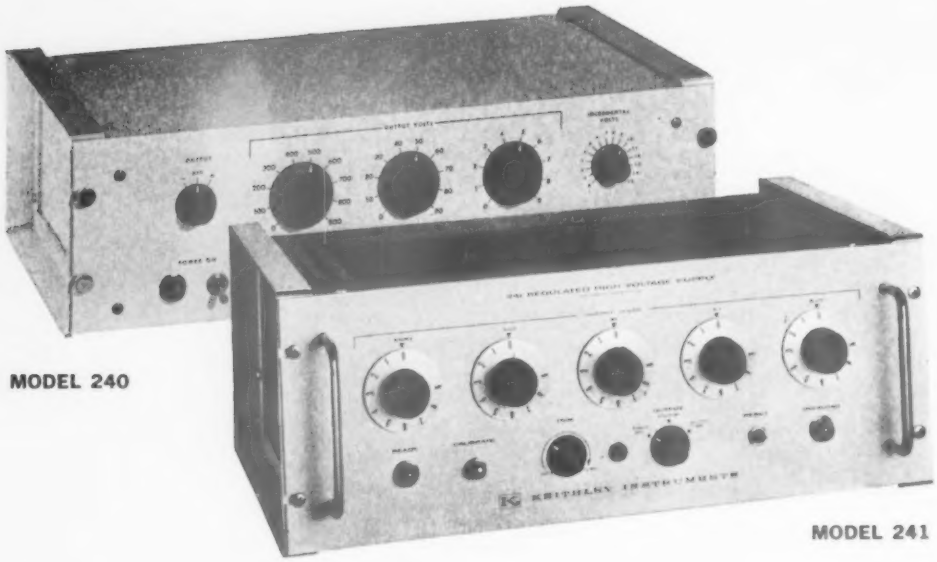


MODEL 240

MODEL 241

pick the accuracy you need from these Keithley high voltage supplies

MODEL 241 – *0.05% accuracy*

Here is the successor to dc secondary standards that employ mechanical choppers and standard cells. The new 241, featuring a Keithley-designed long-life photo-chopper, offers five-dial resolution from 0 to 1000 volts at up to 20 milliamperes. Stability is within 0.005%. Output — plus, minus or floating — can be dialed from 0 to 1000 volts in 0.01 volt steps, with noise and hum below 1 mv RMS. The 241 is unaffected by shock or vibration and cannot be damaged in ordinary use. It is most useful in calibration of meters and transducers, testing insulation and leakage resistances, and as a voltage reference for analog computers.

MODEL 240 – *1% accuracy*

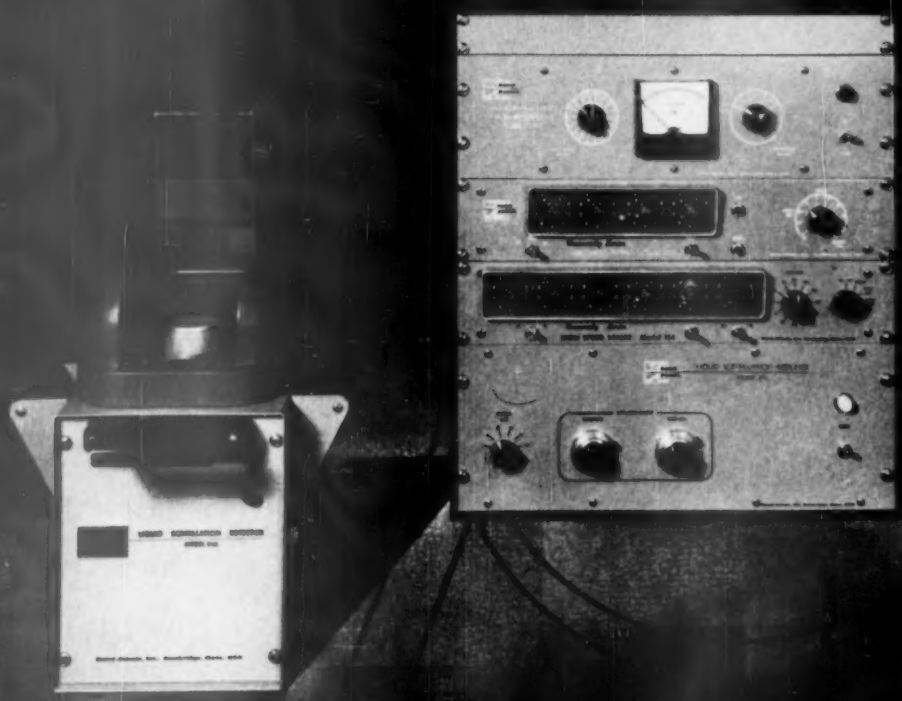
This voltage supply is a general-purpose version of the 241, with similar features and somewhat reduced accuracy and regulation. Three calibrated dials permit dialing any output to 1000 volts in one-volt steps. The switch includes an "off" position, facilitating timed measurements. Stability is within 0.02 volts ±0.02% the first hour, or in subsequent 24-hour periods. The Model 240 can be used to furnish stable dc potentials in checking dc amplifier gains, and for production tests of transistors. Used with a Keithley electrometer, resistances over the range of 0.1 ohm to 10^{16} ohms can be measured.

brief specifications

Model	Output				Regulation			Price
	Voltage	Current ma	Accuracy	Z ohms	Ripple	Line	Load	
241	0-1000	0-20	.05%	.05	1mv	.005%	.005%	$800.00
240	0-1000	0-10	1%	15	3mv	.02%	.02%	$325.00

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE CLEVELAND 6, OHIO

Baird-Atomic pioneers LOW COST liquid scintillation



The development, field test, and customer acceptance of a versatile radioisotope manual liquid scintillation counting assembly has been completed. Here is a system for Carbon 14 and Tritium that incorporates simplicity and flexibility – that is in the price range of all laboratories.

Among its field proven features: simplified circuitry which assures reliable operation, negligible field maintenance; the high voltage supply, scaler and timer are all standard B/A instruments – they can be used with other systems and tailored to your special needs; specially designed, dark preadaption sample holder accepts a variety of sample configurations and sizes; the system is compact and versatile.

These – and other features of the Model 745 Liquid Scintillation unit – are available at the lowest cost you would expect to pay for reliable performance with liquid scintillation. You owe it to your budget to get more information – write or call your nearest B/A representative today.

Sales and service offices in: Cambridge, New York, Philadelphia, Pittsburgh, Cleveland, Washington, D. C., Atlanta, Dallas, Chicago, Los Angeles, San Francisco, Ottawa, Canada.

BAIRD-ATOMIC, INC.

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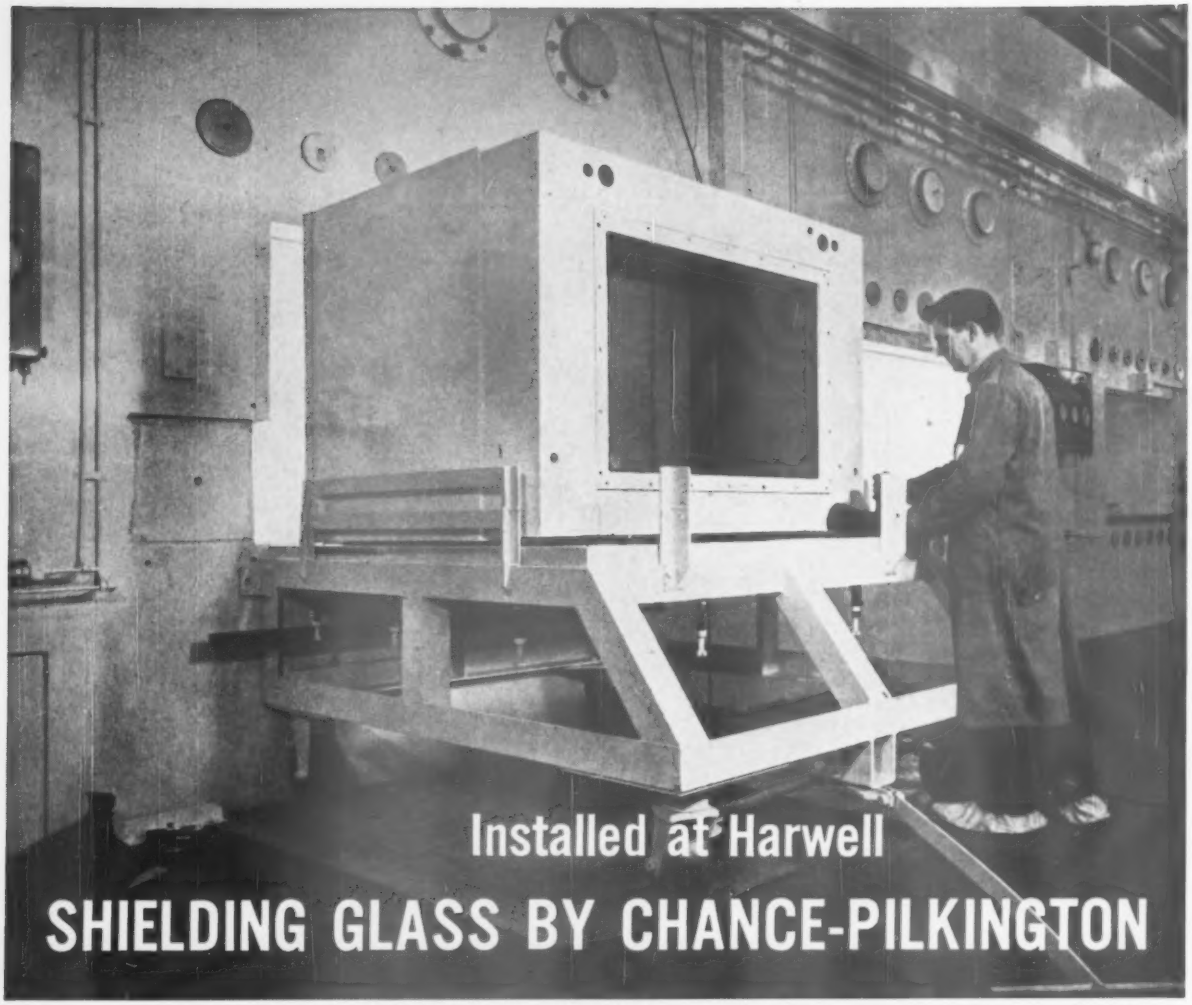

Photograph : A Chance-Pilkington window being inserted at Harwell. (Photograph by kind permission of U.K.A.E.A.)

There are two very important points about this Chance-Pilkington shielding window, shown here under installation at Harwell. First, it is being "cold" side loaded. And second, it is exceptionally large in area. Two of the latest techniques employed are :

1. "Cold" side loading. To facilitate fitting and removal of window assemblies, Chance-Pilkington make available windows suitable for "cold" side loading.

2. Alpha Sealing Window Apertures. "Cold" side loaded windows can include alpha seal plates to prevent alpha contamination leaking to the "cold" side should the windows be removed.

Physicists can save time and money if at an early planning stage they consult the Chance-Pilkington Advisory Service, regarding the design of the window and the window aperture. We supply efficient shielding windows at low cost.

Obviously you will need fuller information than we can give here.
Please communicate with :

CHANCE-PILKINGTON OPTICAL WORKS
PILKINGTON BROTHERS LTD., RADIATION SHIELDING DEPT.,
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6231-P

RCA 25 KW R-F Load and Wattmeter lets you measure power output up to 890 MC

Combines dummy load and r-f power measurement function—Power indication given directly in watts—Easily installed—Used in high power applications for many years.

A column of tap water is used for power dissipation. The input of the load consists of a polyethylene transformer section to match the connecting line. The opposite end of the line is short-circuited and contains the input and output water connections. Broadband wattmeters with scale ranges of 0 to 15 KW or 0 to 25 KW are available. These allow direct incident power readings, or with a 180° turn, a reading of the reflected power.

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25 KW R-F Load Assembly for frequency range 470-890 megacycles . . . Specify MI-19198-A2	Price	$1,050.
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A new and extremely versatile scaler for use with G-M, scintillation, or proportional detectors — with outstanding features as:

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- PRESET TIME AND PRESET COUNT OPERATION
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- SCALER/COUNT RATE METER CAPABILITY
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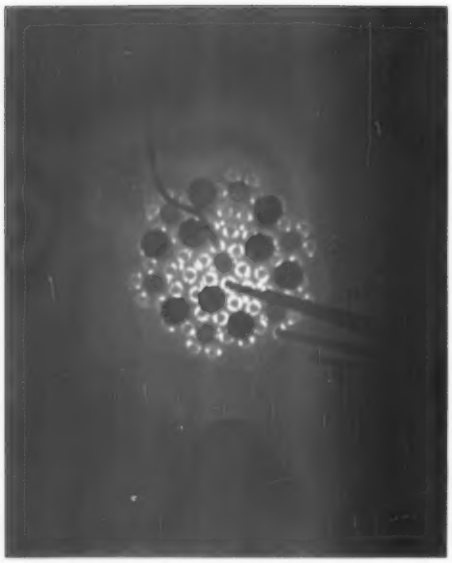
INSTRUMENT AND RESEARCH DIVISION

DENVILLE, NEW JERSEY

60,000 kw Westinghouse testing reactor speeds radiation tests for industry and government



Reactor Core. Nuclear fuels and other materials can be tested inside cylindrical fuel elements.

Testing Reactor Facility. Most powerful privately-owned complete facility in U.S. Available to serve industry and government.

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Remote Handling Facility. Hot cells and metallographic cells are available for post-irradiation examination of samples.

Master Control Room. This is focal point of the operating facility; providing remote indication of reactor performance and experimental conditions.

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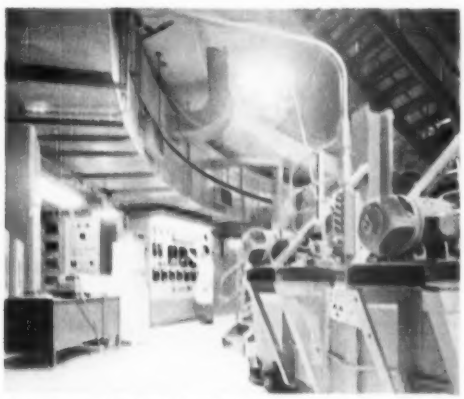
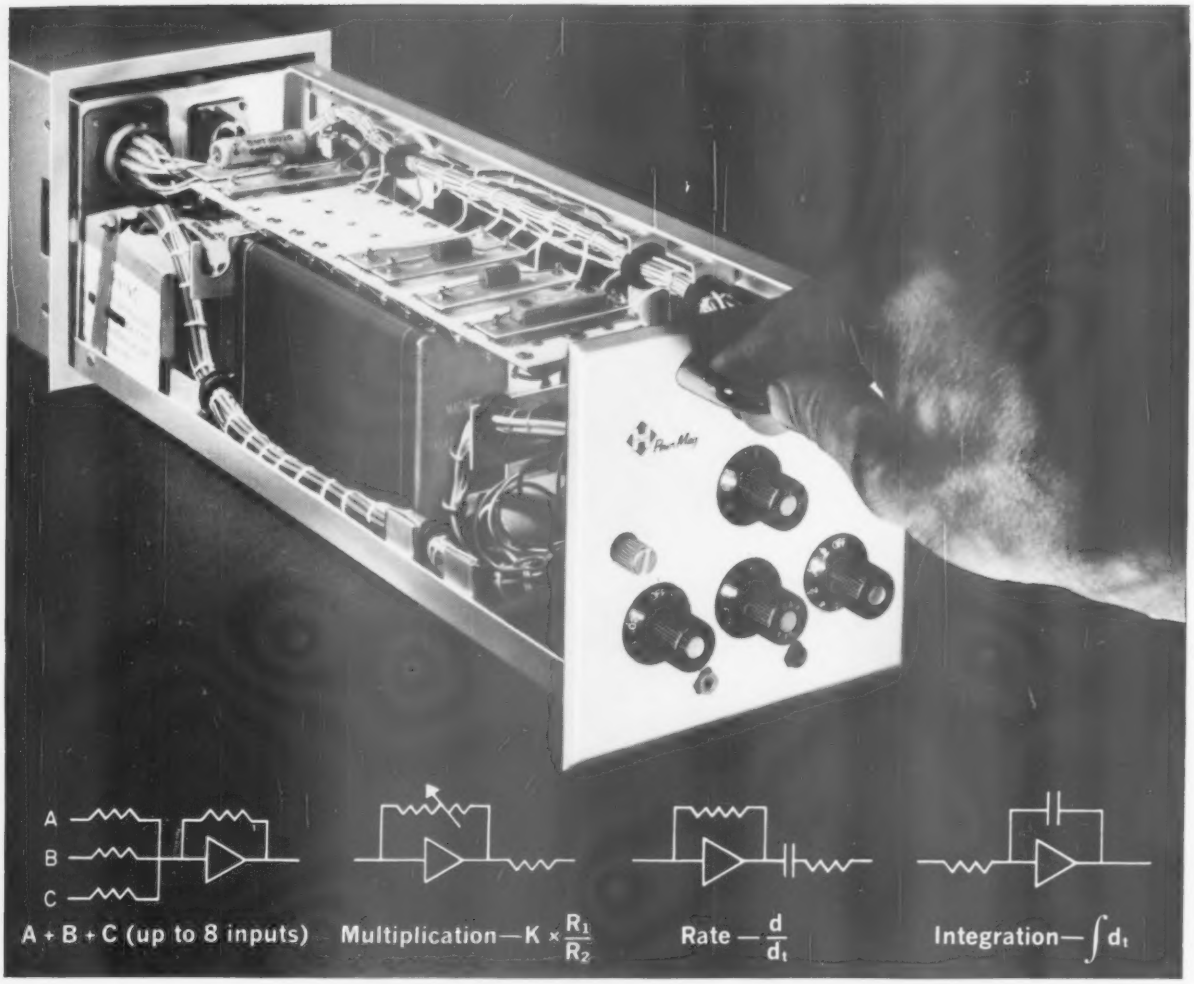


Test Loop Control Center. Loops are available to provide a variety of environmental conditions during irradiation.

11 59502

Westinghouse

Westinghouse Testing Reactor
Box 868, Pittsburgh 22, Pa.



for Atomic Power Plants...
Hagan PowrMag® Controller—solid state reliability

Hagan's PowrMag controller combines the kind of reliability required by atomic power plants with a flexibility of application that makes this one controller suitable for all control actions. Utilizing a high gain, operational magnetic amplifier, PowrMag can produce the full range of control actions by simple negative feedback through ordinary resistors or capacitors. These "passive network" elements are simply and easily plugged into the basic amplifier chassis by means of an integral plug-board, as shown in the photograph.

The PowrMag system uses high level control signal DC voltages which eliminates noise, capacitive loss and phase shift problems. This electrical transmission of sensing unit signals as well as control signals eliminates the use of pneumatic lines in problem areas. The entire amplifier is first potted, then cased in steel. Since any unit can perform any control action by a simple change of plug-in components, inventory and stocking problems are eliminated. Power supply is unregulated 110vAC, and power consumption is three watts.

Each module is equipped with a pilot light to indicate fuse failure, test jacks to plug in an output meter, calibrated knobs for set point (bias), gain, reset and rate. Controller components can be replaced without a soldering operation.

The complete PowrMag line includes the controller, remote control stations, sensing elements, and final operators. For information on the application of Hagan equipment to atomic power plants, write or phone NUCLEAR POWER DIVISION, Room 808, Hagan Center, Pittsburgh 30, Pennsylvania.

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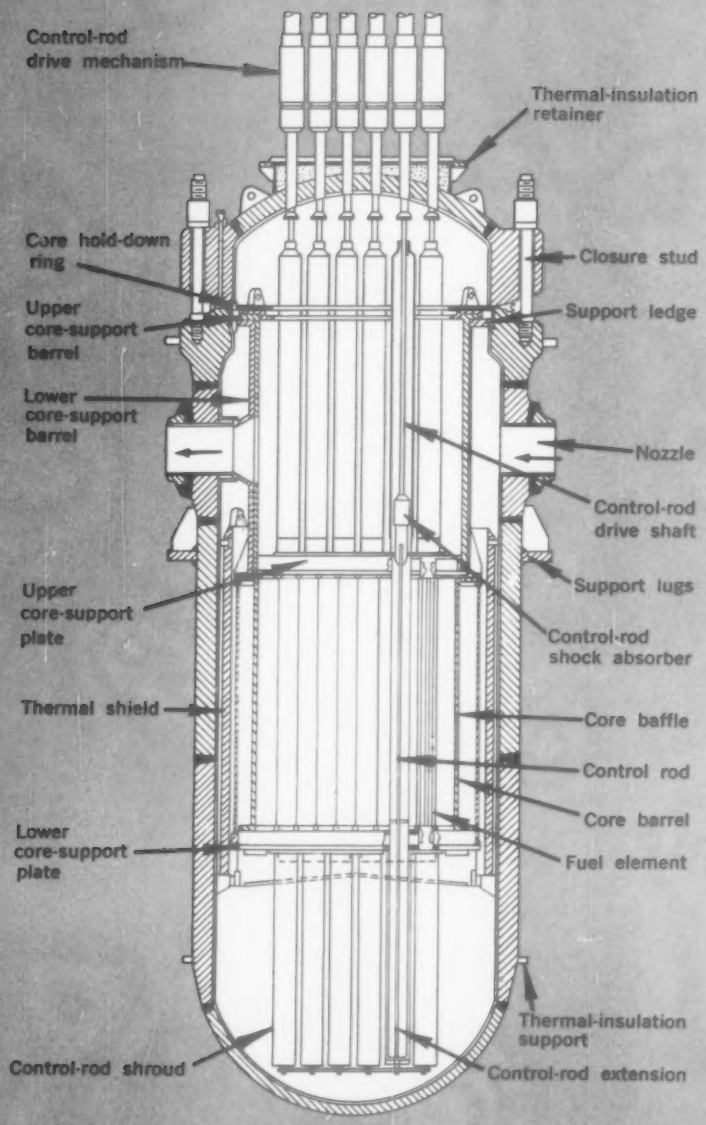
HAGAN DIVISIONS: CALGON CO. • HALL LABORATORIES • BRUNER CORP.

REACTOR FILE...NO. 9

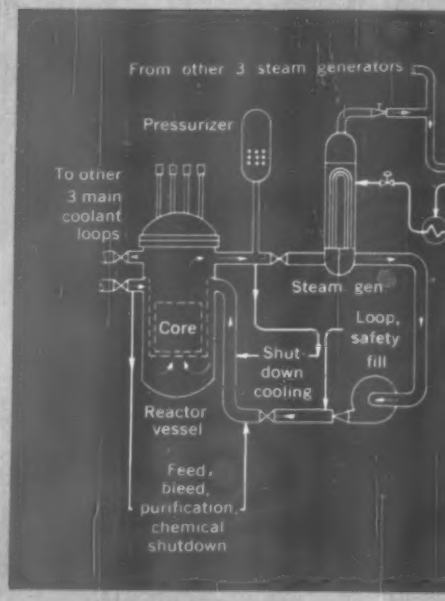
YANKE

The Yankee reactor went critical on Au
nating about two and a half years of
compared with plant construction and s
basis, Yankee's approach has been mor
practice—in which the utility plays a ma
dination and startup. This method has
Yankee, probably because its staff was
its role. In other cases, Yankee feels an
between "conventional" and "turnkey"

The first months after criticality we
training and core-physics testing at
November 10 the plant first fed electric
land grid. Up until January 2, 1961, the
(separating the turbine-generator from t
two were scheduled for gathering nucle
were for turbogenerator testing and me
During this time the reactor was critica
turbogenerator operated 688 hr while
kwh gross (36,184,000 net). On Januar
reached its full licensed power of 110 M
500-hr run, which is required under
license. There were three shutdowns d



1 Reactor vessel, whose 8-in. walls of carbon steel SA-302B are clad inside with 0.109 in. of type 304 s.s., has been tested hydrostatically at 3,435 psig three times. The closure, with 52 studs and double self-energizing O-ring gaskets, has not leaked at all, so seal-welding has not been necessary. Each stud is 5¼-in.-diameter SA-193-B16 carbon steel. The closure nuts are of SA-194-2HB carbon steel. A tap for periodically monitoring for water leakage between the inner and outer O-ring gaskets penetrates the reactor head bolting flange



2 Each of the four parallel closed piping loops
shell-and-U-tube steam generator, a single-spee
a swing-type 20-in. check valve, two gate-type s
steel piping and instrumentation for pressure, t
nections for auxiliaries and a bypass line around
145 Mw at 3.5 in. Hg abs back pressure with 3%
1,840,000 lb/hr (1,480,000 at 110 Mwe) steam
with 0.25% moisture

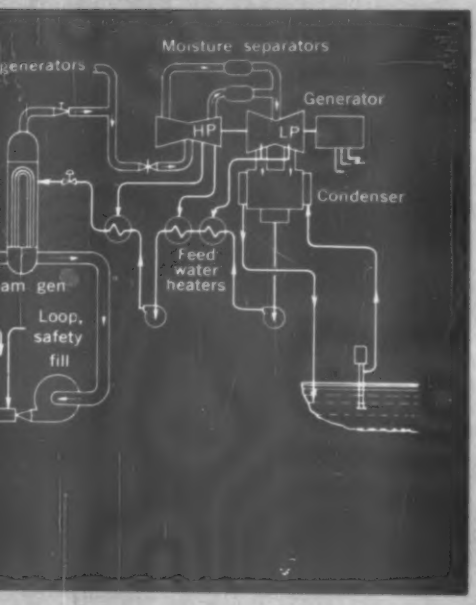
KEE on the Line

critical on August 19, 1960, culmi-
half years of construction work. As
struction and startup on a "turnkey"
has been more akin to conventional
ity plays a major role in design coor-
s method has worked quite well for
e its staff was very well prepared for
ankee feels an approach somewhere
nd "turnkey" would fit best.
r criticality were used for operator
s testing at low power levels. On
irst fed electricity into the New Eng-
y 2, 1961, there were 15 shutdowns
enerator from the transmission grid);
gathering nuclear data, the other 13
esting and mechanical adjustments.
tor was critical for 1,655 hr and the
688 hr while producing 41,694,000
et). On January 17, 1961, the plant
ower of 110 Mw(e) net and began a
quired under Yankee's provisional
e shutdowns during the 500-hr run,
which ended February 8, 1961. On January 22 the reactor was shut down for 6 hr to check natural-circulation cooling. When one turbine-trip switch was thrown accidentally on January 25 the plant was off the line for 1¾ hr. The steam lines were inspected for evidence of a suspected leak during a 2-hr shutdown on January 28 (actually, no leak had occurred). Throughout the 500-hr run the plant continued to respond nicely to all control directions. The turbine and in-core monitoring system, which had given trouble earlier, performed faultlessly.

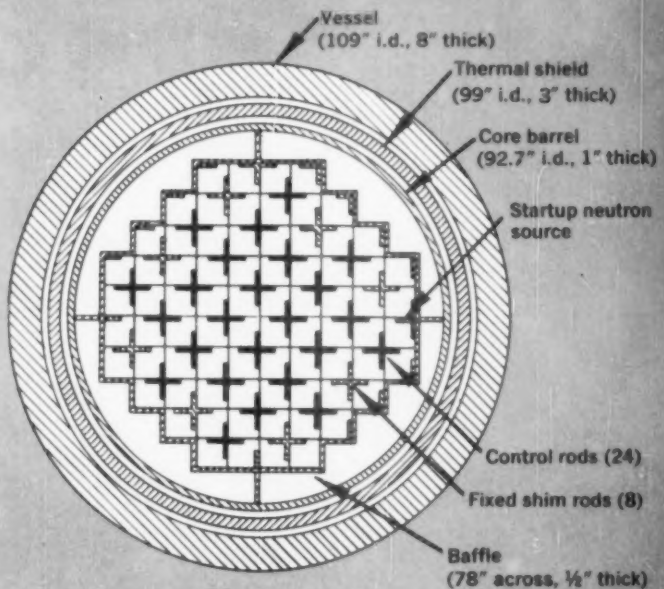
While the plant staff numbered 90 persons during core loading and initial startup, only 65-70 men are involved in operating the plant now. This is fewer than for a conventional plant of the same output, but the staff includes 12 professional men who supervise technical operations.

Yankee operators expect that it will take about 2 hr to restart the plant after a shutdown where the reactor remains hot, while it would take about 2 days to get up to full power after a cold shutdown.

The second core, which will be a near-duplicate of the first, will be fabricated by Westinghouse and ready for installation by about February, 1962. In the meantime, thought is being given to development work needed for an advanced Core 3.

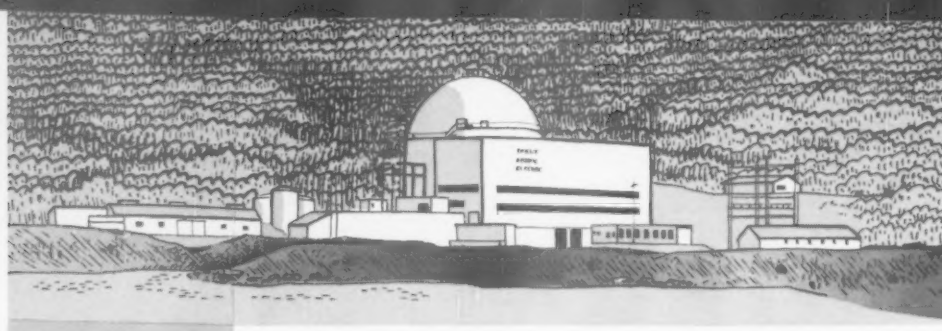


d piping loops in the primary system has a vertical
a single-speed 23,700-gpm canned-motor pump,
wo gate-type stop valves, 20- and 24-in. stainless-
for pressure, temperature and flow, as well as con-
ss line around the reactor. Steam turbine, rated at
ssure with 3% makeup, operates at 1,800 rpm with
0 Mwe) steam at 460° F (472) and 453 psig (510)



3 Core section shows location of control rods, shim rods, and fuel elements. Center tube in 19 fuel elements in one quadrant of core (and in one fuel element in each other quadrant) is used for inserting activation wire for measuring neutron flux along core height. Core exit water temperature is monitored continuously to ±2-5° F by 27 thermocouples that show power and temperature shifts. Baffle separates water flowing down outside core from that flowing up inside

ne Line



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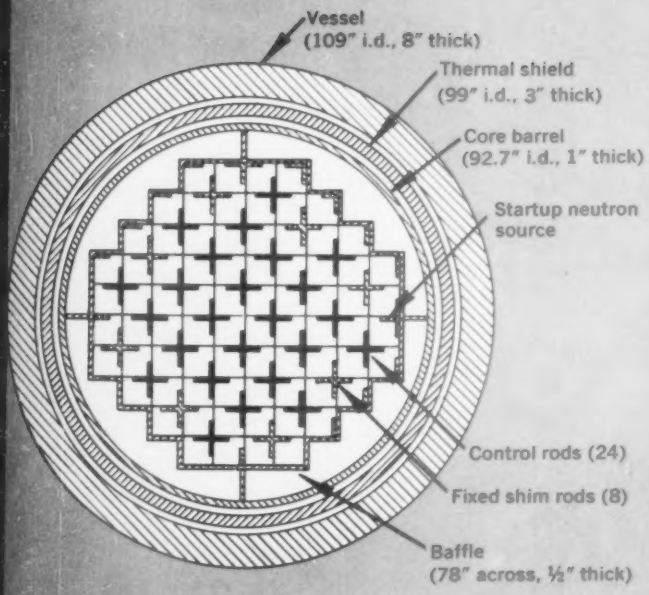


3 Core section shows location of control rods, shim rods, and fuel elements. Center tube in 19 fuel elements in one quadrant of core (and in one fuel element in each other quadrant) is used for inserting activation wire for measuring neutron flux along core height. Core exit water temperature is monitored continuously to ±2–5° F by 27 thermocouples that show power and temperature shifts. Baffle separates water flowing down outside core from that flowing up inside

Characteristics of YANKEE

Location • Rowe, Massachusetts
Owner & Operator • Yankee Atomic Electric Co. (10 New England Utilities)
Reactor-system design • Westinghouse Electric Corp.
Construction; plant design • Stone & Webster Engineering Corp.
Output—heat • 485 Mw(th) (392 initially)
—net electrical • 136,000 kw(e) (110,000 initially)

Component Design Data

Pressure vessel

		Material:	SA-302B carbon steel
Outside height; i.d.:	31.5 ft; 9.1 ft	—inside clad	0.109 in. 304 s.s.
Wall thickness:	8 in.	Design pressure:	2,500 psig at 650° F

Core

Size: 75.4 in. dia x 91.86 in. (cold)

Composition (at 514° F):	UO_2	Gap	SS-348	Zircaloy—2	Wat
—gm/cm³	10.10	—	7.80	6.51	0.7
—in.³	143,025	6,725	48,219	12,137	201
—lb	52,190	—	13,588	2,855	5.6

Fuel elements

Type:	UO_2 pellets in s.s. tubes	Pellet size:	0.294 in. dia x 0.6
Enrichment:	3.40%	Cladding:	348 s.s.
Number:	76 fuel elements; 23,142 tubes; 3,470,000 pellets	—wall; i.d.:	21 mil; 0.298 in.
		Burnup, avg:	7,830 Mwd/tonne
Rods/element:	304; 305 (in other 38)	Endurance:	10,000 hr @ 392
Rod spacing:	0.422 in. centers	UO_2 max. temp:	4,330° F
Element size; wt.:	7.61 in. sq. x 111¼ in. over-all; 890 lb	Clad max. temp.:	663° F
		Heat surface:	15,500 ft²
		Pellets/rod:	150 (25 x 6)

Control rods

Shape; no.; size:	cruciform; 24; 7.865 in.	Weight/rod:	190 lb (355 with Z
Absorber length:	90.5 in.	Withdrawal rate:	6 in./min
Absorber material:	80 wt% Ag, 15 wt% In, 5 wt% Cd	Scram time:	< 2 sec
		Rod cladding:	0.5-mil Ni
		Drives:	Latch-type magnet

Nuclear Design Data

Th.-neut. φ, avg:	2×10^{13} n/cm²/sec	Control requirement:	
Avg neut. energy:	~ 0.07 ev	Fuel burnup:	6.9% Δk/
Prompt-neut. life:	1.85×10^{-5} sec	Equilibrium Xe & Sm:	3.2% Δk/
Eff. delayed-neutron fraction:	0.0071	Hot to cold:	7.2% Δk/
		Doppler (0-full power):	2.5% Δk/
Over-all temp. coef.:	-2×10^{-4} Δk/k/° F	Total:	19.8% Δk/

Control capability—total rod worth: 17% Δk/k; —boric-acid worth: 8% Δk/k

Heat Transfer Data

Coolant:	H_2O	Operating pressure:	2,000 psig
Volume:	24,000 gal. total, 870 in core	Pressure drop:	16 psi core,
Flow:	14 ft/sec avg ±7% (core)	Core flow area:	15.4 ft²
	34×10^6 lb/hr (core)	Core heat flux:	
	3.8×10^6 lb/hr (reflector)	—average:	86,300 Btu/h
Temp.—inlet:	496° F	—maximum:	446,300 Btu/
—outlet:	533° F	—burnout:	980,000 Btu/

NUCLEONICS
REACTOR
FILE . . . NO. 9

Reactors on the Line

YANKEE

Yankee
Atomic
Electric
Power
Station

E

es)

a

steel
s.
0° F

6 in. (cold)

Zircaloy–2	Water
6.51	0.7814
12,137	201,065
2,855	5,675

0.294 in. dia x 0.6 in.
48 s.s.
1 mil; 0.298 in.
,830 Mwd/tonne
0,000 hr @ 392 Mw(th)
,330° F
63° F
5,500 ft²
50 (25 x 6)

90 lb (355 with Zry)
in./min
< 2 sec
5-mil Ni
atch-type magnetic jack

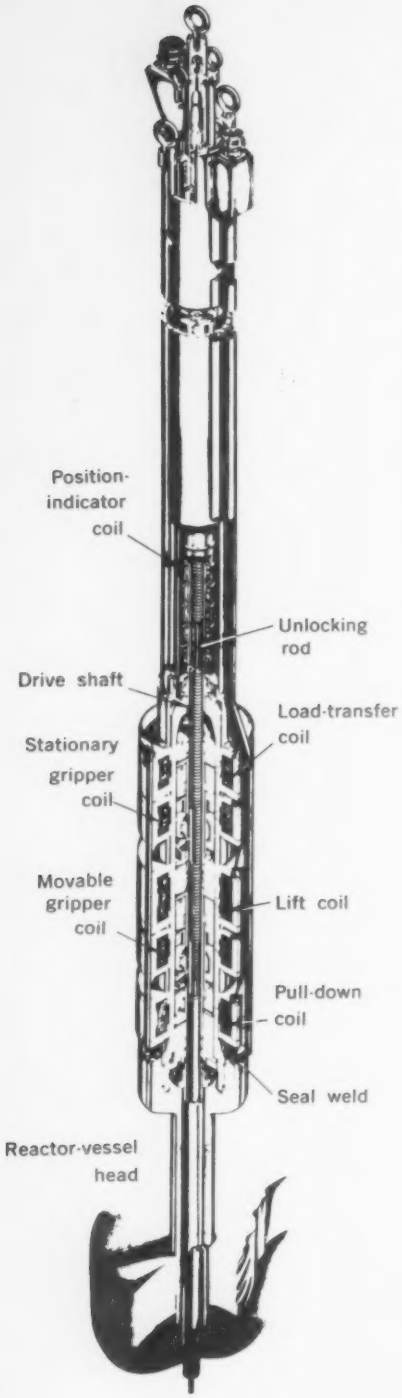
	6.9% Δk/k
m:	3.2% Δk/k
	7.2% Δk/k
er):	2.5% Δk/k
	19.8% Δk/k

Δk/k

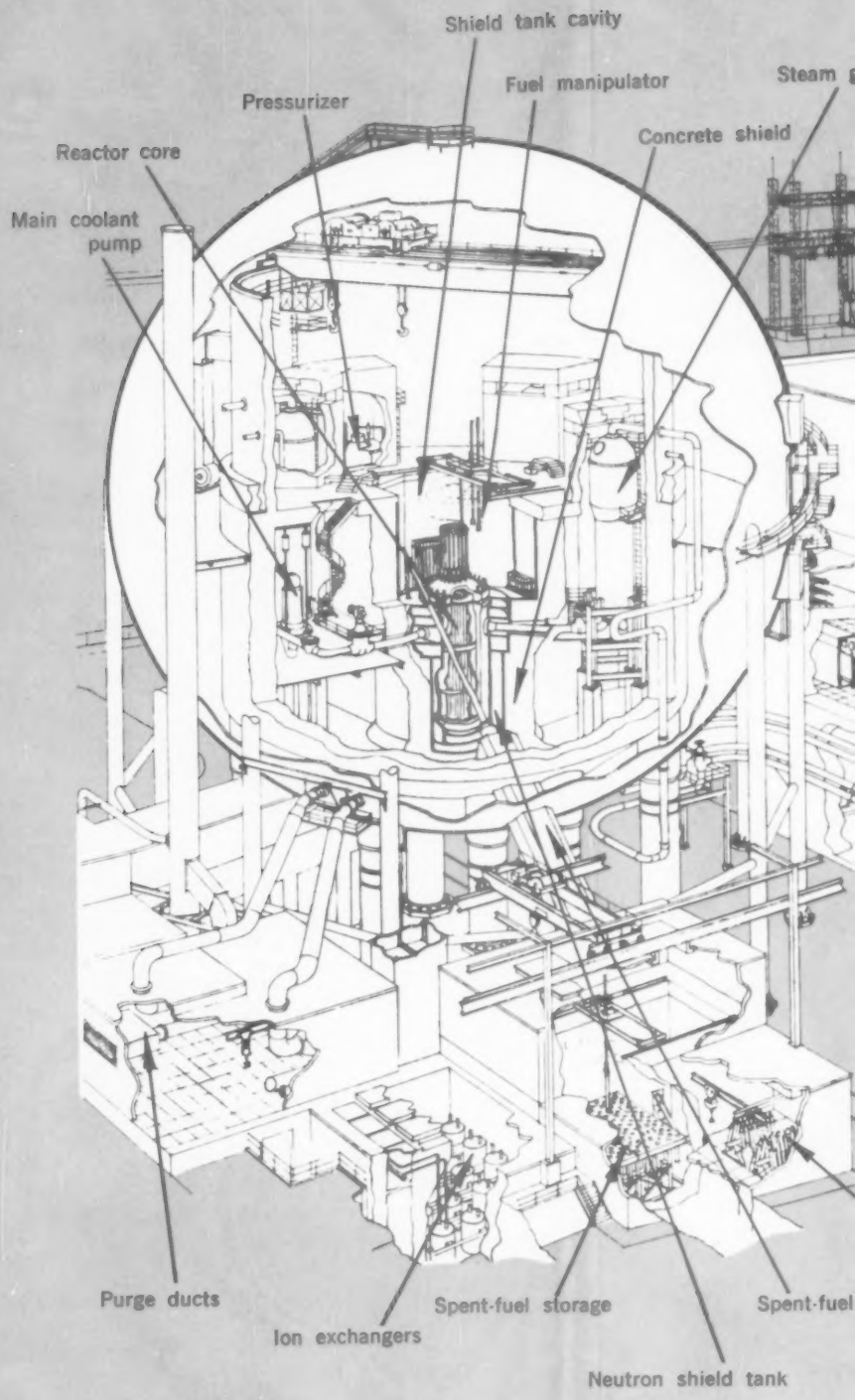
2,000 psig
16 psi core, 34 vessel
15.4 ft²

86,300 Btu/hr/ft²

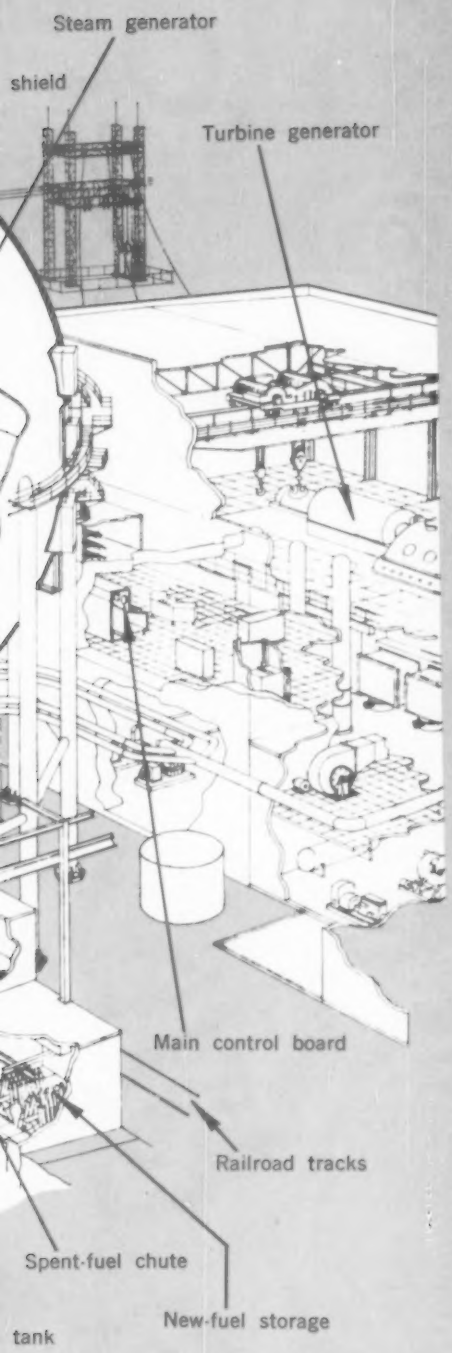
446,300 Btu/hr/ft²
980,000 Btu/hr/ft²



4 Latch-type magnetic jack mechanism drives each of the 24 control rods. Electromechanical system (not shown) indicates position of each rod exactly, but lights on control panel tell approximate position via inductance changes in series of hollow transformers along length of each control rod



5 Unlike most nuclear plants, Yankee's containment vessel is wholly above ground – in fact, it is elevated atop sixteen 42-in.-dia columns. Although this makes pipe runs long and costs more to build than in-the-ground containment, all the welded seams can be inspected inside and out, and equipment installation, maintenance and replacement can be performed independently and fast. Large components are brought by r
sphere, then the crane v
equipment up through a
sphere. For instance, eac
generator was installed
struction was not delaye
receiving the reactor v
about 3% of the electric



brought by rail to a position under the
n the crane within the sphere lifts the
p through a hatch in the bottom of the
instance, each 38-ft-high 120-ton steam
as installed in 6 hr; and over-all con-
s not delayed by a 4-month delay in
e reactor vessel. Yankee will supply
f the electrical needs of New England

Description of YANK

The heart of the Yankee plant is a light-water-cooled and -moderated pressurized reactor whose core consists of 3.4%-enriched UO_2 pellets in stainless-steel tubes. Fission heat in the reactor raises the 2,000-psig closed-cycle water to ~529° F before it passes through four vertical steam generators (in parallel) to produce steam on the secondary side at about 467° F and 500 psi. This steam is led off to a conventional turbine-generator in a separate building. Novel features include:

- A wholly above-ground and elevated containment sphere for easy inspection and equipment installation and maintenance.
- Use of boric acid solution in reactor water during cold shutdown so as to depress reactivity.
- An in-core instrumentation system (flux wires, thermocouples) for monitoring power generation; flux-monitoring wires can be inserted remotely into a tube in 22 of the 76 fuel elements during operation—automatic readout is provided in the control room (it takes 75 min to read flux along height of 1 fuel element, 110 min to read 8 elements and 3 hr to read all 22).

Vessel and Shielding

The reactor vessel, the largest single component in the main coolant system, is a vertical cylinder with hemispherical heads. For corrosion resistance, this carbon-steel vessel is clad inside with stainless steel. The flanged top closure, from which the control-rod drive mechanisms are supported, bolts to the flanged cylinder. The reactor coolant enters and leaves the vessel through four pairs of nozzles spaced uniformly above the core.

Between the fueled core and the 8-in.-thick carbon-steel reactor vessel around the core there is a ½-in.-thick core baffle, a 1-in.-thick core barrel and a 3-in.-thick thermal shield of 304 stainless.

A neutron shield tank around and under the reactor vessel contains a 36-in. thickness of water. Pie-shaped canned masonite shield blocks cover the gap between the core vessel and shield tank at the top of the vessel so as to attenuate neutrons streaming upward between the vessel and tank. Beyond this shield tank there is a reactor or "primary" shield made of reinforced concrete that is 5½-ft thick up to the vessel flange height, 4½ ft above. The concrete "secondary" shield, which surrounds the entire reactor system within the vapor container, is 5½ ft thick up to the charging floor, 2 ft above.

Core Structure

The reactor core structure consists of an upper and lower core-support plate, an upper and lower core-support barrel, a core barrel and a baffle structure.

The 76 fuel elements are in a close-packed square lattice; holes in both support plates help position the fuel assemblies and also act as coolant inlet and outlet nozzles for the fuel elements. Each support plate is a rigid assembly of two perforated plates joined by 76 sleeves welded directly to the plates. The sleeves, together with spacer rings on the outer edge of the plates, stiffen the two plates and form a rigid sandwich-type support structure.

The 1-in.-thick 7¾-ft-i.d. core barrel is between the baffle structure and the thermal shield; the lower core-support plate is doweled and bolted to the lower rim of this barrel. The entire core-support structure rests as a unit on a ledge within the vessel.

Fuel Elements

The solid cylindrical pellets of 3.40%-enriched UO_2 are stacked in the fuel tubes in groups of 25. Groups are separated by a perforated stainless-steel disk coated with braze material. Each disk has a circumferential groove into which the tube is crimped when the pellets are loaded, fixing its position until the entire subassembly is brazed. The disks are spaced so that each group of 25 pellets has a free expansion space. Stainless-steel end plugs are welded onto the ends of each tube.

Fuel rods are held in 6 × 6 subassemblies by brazed ferrules that maintain structural rigidity and spacing between rods. Nine of these subassemblies are strapped together to form a complete fuel element, of which there are 76. Two element shape variations (38 with 304 rods, 38 with 305 rods) provide 32 cruciform slots in the core for inserting the 24 control rods and eight shim rods.

Control and Shim Rods

The 24 reactor control rods consist of nickel-plated silver-indium-cadmium alloy (80-15-5%, respectively). Connected to the active portion of the control rod is a Zircaloy-2 rod follower that also prevents excessive bypass coolant flow through the control-rod channel.

Each of the eight cruciform shim rods has a boron–stainless-steel section and a Zircaloy-2 section. The rods are fabricated so that either section can be placed in the active portion of the core, where they remain motionless until adjusted by the operators after the vessel head is removed. The Zircaloy-2 follower sections are in the core at the present time.

Control-Rod Drives

Each of the 24 control rods is driven by its own positive-grip magnetic-jack mechanism. The only drive components that operate in the high-pressure high-temperature main coolant are the drive shaft, the movable and stationary grippers, and the solenoid plungers that actuate the grippers—all these are enclosed in a pressure housing seal-welded to the reactor-vessel head.

The electromagnetic coils that actuate the solenoid plungers (and, in turn, the grippers) are mounted on the outside of the pressure housing. Coil action is programmed so the stationary and movable grippers alternately engage the grooved drive shaft; the stationary gripper holds
able gripper goes to a new
lower the control rod throug
movable and stationary gr
the latches engage and di
grooves without load—this
wear. The operating cycle i
of cams driven by a fixed-sp

The control rods can be s
by de-energizing all coils—
to fall fully into the core
Power failure also de-energi
an immediate scram; the
absorbs rod impact throu
sorbers.

Refueling

When the reactor is shut d
the reactor water cools belo
will be injected into the syst
After power to the control-r
rods will remain fully dow
mechanisms stay mounted o
their shield support is remo
and the level of water in th
draining. Then the operat
electrical cables from the co
coil stacks off the mechanis
trol-mechanism cooling du
instrument thimbles and
insulation from the vessel h
help remove the 52 stud n
water-tight plugs in 48 stud
in the other 4 holes, use th
vessel head ¼–½ in., fill the
water and equalize water le
tem, remove the head and st
handled tools to remove the
disconnect the control-rod d
sorber sections, and use long-
to remove spent fuel elemer
them on a carriage for transf
age pool. Yankee hopes th
eventually will be coincident

Containment Shell

The entire reactor, p
(pumps, valves, steam ge
pressurized auxiliaries are s
dia ≥7⅛-in.-thick spherical
ever the reactor is critical o
at temperature and pressu
sphere can contain pressure
would occur if all the coolant

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2. "Initial Startup Operations of th
Report No .1 for period July 9, 19
Atomic Electric Co., Rowe, Mass

IKEE

gripper holds the shaft while the mov-
oes to a new location so as to raise or
rol rod through each ⅜-in. step. The
stationary grippers are positioned so
ngage and disengage the drive-shaft
ut load—this minimizes friction and
erating cycle is programmed by a series
by a fixed-speed motor.
rods can be scrammed at any instant
ng all coils—allowing the control rods
nto the core by gravity within 2 sec.
also de-energizes the coils, resulting in
scram; the upper core-support plate
impact through hydraulic shock ab-

actor is shut down for refueling, before
ater cools below 485° F borated water
into the system to control reactivity.
the control-rod latches is shut off, the
ain fully down in the core (but the
ay mounted on the vessel head); then
pport is removed from over the vessel
of water in the reactor is lowered by
en the operators will disconnect the
s from the control-rod drives, lift the
the mechanisms, disassemble the con-
cooling ducts, disconnect in-core
imbles and thermocouples, remove
the vessel head, use stud heaters to
he 52 stud nuts and washers, place
gs in 48 stud holes, install guide plugs
holes, use the polar crane to lift the
½ in., fill the tank cavity with borated
alize water level in entire reactor sys-
e head and store underwater, use long-
to remove the fuel hold-down plates,
control-rod drive shafts from the ab-
and use long-handled tools and crane
t fuel elements one-by-one and load
age for transfer to the spent-fuel stor-
nkee hopes that refueling operations
be coincident with turbine overhaul.

Shell

reactor, primary-coolant system
s, steam generators, etc.) and its
xiliaries are sealed within the 125-ft-
ick spherical vapor container when-
r is critical or the primary system is
e and pressure. This containment
tain pressures up to 34 psig, which
all the coolant water flashes to steam.

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Yankee Reactor Operates On Schedule, Below Budget

By refining pressurized-water reactor technology, the designers of Yankee have produced a system that zeros in on a practical utility power station. Construction and operating costs benefit from the straightforward approach

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THE YANKEE REACTOR went critical last August, two months ahead of schedule. Experience since then in taking the plant up to design power shows that even in a relatively straightforward design mechanical problems can loom large when trying to put a nuclear power station into routine operation. Despite these problems, its good points make Yankee shine brightly in the growing constellation of nuclear power stations.

- Yankee attained criticality about two months ahead of schedule.
- Yankee total capital costs are working out to be substantially less than the $57-million that had been estimated before construction began back in 1957 (see box at right).
- Nuclear troubles have been very few.
- Except for the mechanical troubles during startup, the plant operates smoothly—with present indications showing competitive nuclear power in New England somewhat sooner than estimated previously.
- The plant has a number of unique features (see p. 53) that will help it to serve as a commercially and routinely operated plant. Also, since the turbogenerator has a rated output of 145 Mwe (gross) and a probable capability of 160 Mwe, there is room to increase power after operating experience is acquired. This together with improvements in fuel cost and performance will bring the 136-Mwe 11–15-mill/kwh (8–10 mills/kwh for capital + 3–5 mills/kwh for fuel and operation) nuclear-power cost nearer the 9-mill/kwh cost now typical in New England.

When the ten New England utilities that own Yankee decided back in 1954 to build this plant they picked a pressurized-water type reactor because technologically this type was well established, but they resolved to emphasize the commercial aspects of its design and operation. This experience would give valuable background toward building other nuclear plants in New England, where fossil-fired power is costly. Early operating experience and the construction history show where the plant stands today.

Core Loading

After construction work was complete and all the systems were checked out, on July 9, 1960 the U. S. Atomic Energy Commission issued an interim license for Yankee to load fuel, go critical and conduct tests up to 5 Mw(th). Within the next week, the reactor vessel and primary loops were filled with water borated to 1,600 ppm (later 2,100 ppm) and the first of four startup sources was installed on its source vane. (Four Po-Be sources serve for initial startup, then neutrons will activate four Sb-Be sources for subsequent startups; the sources are in stainless-steel tubes mounted on four vertical vanes located 90 deg apart on the edge of the core). After the temporary nuclear instrumentation was modified and a satisfactory base count established, the first of the 76 fuel elements were loaded into the core. Troubles with the fuel-handling equipment and nuclear instrumentation had to be corrected. The temporary neutron detectors had to be moved with respect to the sources and fuel after the first few elements were loaded because they gave a falsely high reading for the multiplication factor. After the core was loaded with fuel on July 26, the source-range detectors were replaced with detectors of

Costs Lower Than Expected

It is too early to be definite about precise capital cost figures, but not too soon to feel certain that they will run well below the earlier estimates of up to $57-million. The final figures for the plant, as a construction project, will run to $38–40-million, divided approximately as:

Land (2,000 acres)	$ 200,000
Structures	8,700,000
Reactor plant equipment	16,800,000
Turbine-generator	8,900,000
Accessory electrical and mechanical equipment	3,500,000
	$38,100,000

To cover organization, taxes, insurance, operator training, interest, engineering and administration, test operation, public relations, etc., a sum of about $7–8-million must be added. Also, the first core costs about $3.2-million (not including reprocessing). Research and development costs have amounted to about $5.3-million, of which $5-million was allocated by the USAEC under its Power Demonstration Reactor Program.

greater sensitivity so as to produce satisfactory readings. Then the rest of the core structure was installed and the head was placed on the reactor vessel and bolted. To test the control-rod drives, each rod was dropped at least twice from the full-out position; all drop times measured less than the calculated 2 sec from initiation of scram.

Criticality, Low Power

The reactor went critical at 8:19 P.M., August 19, 1960 after a smooth two-hour approach in accordance with written procedures. Nuclear instrumentation performed very satisfactorily. It had been calculated that criticality would be reached on a banked rod configuration with rods withdrawn 42 in. But the reactor went critical with less withdrawal, indicating a slightly more reactive core or greater rod worth than expected.

Then the reactor was operated for familiarization and further training purposes. During this period some of the coils for operating the control-rod coarse position were shorting out. Investigation showed that faulty venting might have let borated water leak into the coils, which when it dried up left boron crystals that grounded the coils. This was rectified by drying and cleaning the coils, and by improving the venting arrangement. Beginning September 4th, data were collected at low reactor temperatures so as to calculate control-rod and boron reactivity worths. Then temperature, pressure and flow coefficients of reactivity were measured at various temperatures and control-rod and boron worth were determined at operating temperatures. (With the reactor hot there is a 3% shutdown margin with the rods. But with a new cold core it also takes 1,170 ppm boron as boric acid in the water for a shutdown margin of 5%.) Other tests were run to learn hot scram rates, system heating rates and response of the neutron instrumentation when control rods are positioned asymmetrically. During September and October low-power tests, most of the bothersome troubles were with hardware rather than being of a nuclear variety; about 40% of the low-power-test period involved maintenance of mechanical equipment. Although this maintenance work lost much of the schedule lead, it was used to advantage in that the personnel qualified to operate the reactor increased from 5 to 12 during this time.

Mechanical problems. Most of the mechanical troubles were of the sort encountered in starting a conventional power station, but the addition of nuclear design factors to normal engineer-

Yankee Chronology—Conception to Criticality

August 30, 1954: President Eisenhower signs the amended Atomic Energy Act, which permits ownership of atomic facilities by private companies.

August 31, 1954: New England utilities agree to form Yankee Atomic Electric Company.

March 30, 1955: Yankee submits initial proposal under the AEC's Power Demonstration Reactor Program.

August 22, 1955: Yankee revises proposal for 134,000-kw plant.

February 8, 1956: AEC accepts proposal for negotiation.

June 6, 1956: Yankee signs first contract with AEC under Power Demonstration Reactor Program. A $5-million development subcontract to Westinghouse entails: development of better UO_2 pelletization methods, stainless-steel cladding-tube closures, ways to join fuel rods into bundles using brazed ferrules and straps, optimized core design, analyses of control-rod and chemical-poison effectiveness, plant safety, shielding, steady-state and kinetic performance, planning and analyses of critical experiments, corrosion tests of reactor-system materials, development of water-chemistry techniques and of a water-soluble neutron absorber, mechanical design of the fuel assembly, core supports, control rods and latch-type magnetic-jack drives (tests of loading, reliability, life), fuel-handling devices, critical experiments and irradiation tests (including in-pile loops), thermal and hydraulic design of the reactor system, development of Ag-In-Cd control rod with diffusion-bonded nickel-plate cladding, assistance with startup experiments.

July 1, 1956: Yankee authorizes Westinghouse and Stone & Webster to proceed on plant engineering and design.

July 9, 1956: Yankee applies to AEC for construction permit.

September 4, 1956: Land clearing and background radiation monitoring begin at site. Yankee contracts with Westinghouse Electric Corp. (under effective date 6/6/56) to conduct the research and development program.

April 12, 1957: Yankee submits preliminary hazards report.

November 4, 1957: AEC issues construction permit.

December, 1957: Yankee arranges $57-million financing.

January 24, 1958: Westinghouse begins critical experiments with small-scale model of Yankee reactor core.

March 17, 1958: Excavation starts at site.

April 11, 1958: First concrete foundations placed.

June 20, 1958: First steel erected at site for turbine hall.

September 26, 1958: One of the largest concrete placements —1,000-yd^3 continuous pour made in saucer-like base of internal structure for reactor. Concrete weighs 2,000 tons, reinforcing steel 100 tons.

December 2, 1958: Chicago Bridge & Iron begins to erect 125-ft-dia steel containment sphere.

April 24, 1959: 160-ton generator stator, first piece of major equipment, arrives at site.

April 30, 1959: 70-ton rotor for turbine arrives at site.

June 19, 1959: Successful 40-psig test of steel sphere.

June 24, 1959: Yankee's staff moves to plant site.

October 31, 1959: First fuel elements arrive at site.

February 7, 1960: 165-ton reactor vessel arrives at site; although it was four months late, the elevated-sphere arrangement had permitted other work to continue.

March 31, 1960: Hydrostatic tests of primary system start.

June 6, 1960: All fuel assemblies at site; assembly of reactor-system piping to reactor vessel completed.

June 9, 1960: Operators start to flush reactor system with hot water and check equipment at operating conditions. When the system is shut down after flushing and leaktests, leaks and other troubles are repaired.

July 1, 1960: Construction is practically complete; all systems have been checked out.

July 8, 1960: Yankee asks AEC for operating license.

July 9, 1960: AEC issues interim license that permits Yankee to load fuel, go critical and test up to 5 Mw(th).

July 16, 1960: Yankee begins to load fuel elements into core.

August 14, 1960: With vessel head bolted on, control-rod scram tests begin.

August 19, 1960: Reactor goes critical at 8:19 P.M. As of this date, the reactor is two months ahead of schedule.

ing requirements gave rise to some new problems. For instance, to avoid gasket corrosion if the primary loops were to be decontaminated at some future time, it was specified that copper gaskets could not be used in closures in primary-system components. Thus, hard nickel gaskets (22 mils thick, about 1 in. wide and 4 ft in diameter) were used on the main coolant pumps. Pump flanges deformed badly and leaked after the system was heated up and cooled. After the flanges were scraped flat, the solution involved using soft copper gaskets and relying on differential thermal expansion to provide the final tightening of the closure.

The four check valves in the reactor system have been free of troubles. The eight parallel-disk stop valves hold the 2,000-psi water with very low leakage. Stem packing leakage has been low with the valves in the open-backseated position.

The 18-in.-dia Flexitallic gaskets on the manholes of the four steam generators have been another source of leakage. Although it was eventually possible to tighten the gaskets on the 800-psi secondary side, it was necessary to seal-weld the closures on the 2,000-psi primary side. Another leak occurred in the steam generators between the type-304 stainless steel internal cladding and the carbon steel base metal at a point where the the shell is pierced by a 1-in.-dia stainless-steel instrumentation nozzle welded to the carbon steel.

To prevent the operating coils on the magnetic-jack control-rod drives from overheating (to 600° F instead of the 450° F for which they were designed) it was necessary to reduce the voltage at which they operate as well as to redesign the entrance cooling ducts and provide better baffling to improve air distribution.

The flux wires used in the in-core instrumentation system also gave some problems initially. The Ti-0.3%Mn wires twisted and kinked when they coiled in and out of their shielded storage "barrels" outside the secondary shield. Carbon-steel wires are used now and "in-line" retraction of flux wires is used instead of the barrels. Yankee is counting on the flux-wire system to give a periodic pot of neutron flux inside the core so that control rods can be positioned to keep the flux flat. The center of each of the 19 fuel elements in one quadrant of the core has a vertical thimble through which the flux wire is inserted for irradiation. The other three quadrants each have one fuel element with such a thimble.

To reduce the flux of neutrons streaming up through the annulus between the core vessel and the neutron-shield tank by a factor of about 20, 12–22-in.-thick canned masonite in pie-shaped pieces have been placed over this gap.

Power Tests

On July 29, AEC issued to Yankee a provisional license for power operation up to 392 Mw(th) (110 Mwe net). So after the low-power tests, Yankee started producing electricity on November 10, 1960, and at 2:37 A.M. it first fed power into the New England grid. Plans were to spend 4 to 5 weeks bringing the reactor to the licensed 392 Mw(th) in four steps, while at each step calibrating nuclear instruments and controls, determining power coefficient, transients after loss of load, shield effectiveness, natural-circulation cooling, and reactivity variation caused by fission-product buildup and decay after changes in power. But turbine troubles interfered when the 1,800-rpm turbine reached steam rates where 70–90 Mwe were being generated. Due to partial admission of steam to a lower quadrant of the turbine and to insufficient space to allow the steam that had passed through the impulse stage to distribute around the full 360 deg of the rotor before entering the reaction blading, a large unbalanced pressure resulted across the rotor, lifting it and causing serious vibration. So, on January 2, 1961, the plant was shut down while the two rings that support the first 8 stages of reaction blading were removed and slotted to give space for the steam to flow.

Two weeks later the corrections were complete and the plant was brought to its full licensed power of 120 Mwe gross, 110 net. Yankee then began a 500-hr run to gather data in accordance with license provisions. This run continued with only three minor interruptions and ended February 8th.

What's In Store

Barring unforeseen difficulties, Yankee seems certain to be fully operational before July 1, 1961—the date scheduled for commercial operation.

Since Yankee wants to operate the plant in a way to learn about routine commercial operation of nuclear power stations, research and development programs as such will be held to a minimum. One exception to this has entailed provisions for 12 thimbles for irradiating surveillance specimens of the pressure-vessel steel so as to learn of any ductility loss. Improvements Yankee hopes to make later include: (a) use of small ion chambers instead of wire for the in-core flux plots so as to get immediate readings, (b) operation with 2–5% boron in the water as shim. In any case, routine checks will be made of flux distribution, reactor coolant chemistry, buildup of radioactive contaminants in the loop, power and temperature coefficients of reactivity, shielding, plant and site radioactivity, vapor container leakage, control-rod scram circuits, boric acid safety injection, pressurizer spray and solenoid relief valve, scram alarms, and reliability of instrumentation and power supplies.

In Retrospect

Although Yankee officials are pleased by the way the schedule and cost of the plant have worked out, several things might be done differently if a similar plant were being planned now. Although the use of an elevated containment sphere permits inspection of all its welded seams and the simple installation and replacement of equipment, spent-fuel handling is complicated by the various elevations at which fuel is handled as well as the way it is transferred down to the storage canal. Plant layout also might be made more compact so as to shorten pipe lines. Still more use might be made of dual-purpose storage tanks and the primary auxiliary building might be combined with the waste-disposal facility (as an example of dual-purpose equipment, the present low-pressure surge tank cooling pump also serves for shutdown cooling). Controlled-leakage pumps would be cheaper and might be more efficient than the canned-motor main-coolant pumps. If the core vessel were about 1 ft wider a larger core could be installed for higher power.

Yankee continues to favor an all-stainless-steel primary system because of water-chemistry complication in a system with carbon steel. Yankee also still prefers to use an oversize pressurizer to accommodate surges, rather than transient-control devices with a smaller pressurizer.

AEC's Pittman Reports on

The SL-1 Accident

On January 24 a capacity audience at AEC's Germantown, Md. auditorium listened to AEC's Director of Reactor Development Frank Pittman (above) deliver a technical presentation on the SL-1 reactor accident that had occurred 21 days previously. Because of the great interest in the SL-1 accident NUCLEONICS here presents, in its entirety, Pittman's speech at that meeting. Certain additional information, contained in the January 27 interim report of the official Board of Investigation, is given on p. 64. Broadly speaking, the interim report covers the same ground as the Pittman presentation. Thus what we present here is the latest information available as of the time this section went to press.

A FORMAL BOARD OF INQUIRY has been convened and is in session to investigate the SL-1 incident. Determination of the possible causes of the incident will be receiving a great deal of attention. However, until the Board completes its investigation, firm conclusions are unwarranted. [For highlights of interim report of the Board of Inquiry, see p. 64.—Ed.] Even though the cause has not been determined, I would like to give you a summary of the design features of the SL-1, a resume of the information we have obtained to date, and discuss some of the things which might be the cause or have contributed to the incident.

SL-1 Reactor History

The SL-1 is a direct-cycle, natural-recirculation, boiling-water reactor designed for 3,000-kw gross thermal capacity to produce 200 kw(e) net of electricity and 400 kw net electrical equivalent energy in the form of space heat. Work on this plant started in 1955 in response to a request by the Department of Defense for a small nuclear power plant. The requirement was based on the need to develop such a plant for future application at remote military installations such as Dew Line. Six different reactor concepts were considered, and the boiling-water system proposed by Argonne National Laboratory was selected for development and construction on the basis of compactness, simplicity, reliability, technical feasibility, long core life and minimum plant cost.

ANL undertook the design and development of the SL-1, then designated as the ALPR or Argonne Low Power Reactor. Pioneer Service and Engineering Co. performed the design work on the conventional portions of the plant, and Fegles Construction Co. was used as the general contractor.

Site work began in the fall of 1956; plant construction started in 1957, and initial criticality was achieved in August 1958.

ANL performed the initial criticality and startup tests and successfully completed a 500-hr, full-power, plant-performance test in December 1958. In February 1959, Combustion Engineering, Inc., took over the operation of the SL-1. Since startup the SL-1 has been used to gain operating experience, develop plant performance characteristics, obtain core-burnup data, train military personnel in plant maintenance and operation and test components planned for use in subsequent reactors of this type.

Reactor Description

The SL-1 plant is located at the National Reactor Testing Station about ¾ mile north of Route 20. The site facilities consist of the cylindrical reactor building, an adjoining support building which contains the control room and auxiliary equipment and miscellaneous service buildings (Fig. 1). The majority of the plant equipment is located in a cylindrical steel building 38½ ft in diameter with an over-all height of 48 ft. [See diagram, NU, Feb. '61, p. 20; also NU, Feb. '59, p. 55]. This building is made of steel plate most of which has a thickness of ¼ in. and the building has normal doors. It is not a pressure-type containment vessel as would be used on reactors located in populated areas. The building is located on dummy piles to simulate the type of construction that would be used in the arctic.

The reactor vessel, fuel-storage well and demineralizer are located in the lower third of the building and are

FIG. 1. SL-1 REACTOR (cylindrical building) and support facilities before accident

shielded with gravel. A recirculating, air-cooled condenser is located in the upper third of the building. The middle third of the building contains the turbine generator, feedwater equipment, switch gear and shielding blocks located around the pressure-vessel head. These blocks are moved by an overhead crane to allow access to the pressure-vessel head and the control-rod drive mechanisms.

Core. As shown in Fig. 2 the reactor core is located at the bottom of a pressure vessel with the chimney section above. The control rods are connected to extension rods and racks, and are driven by pinions in the control-rod drive mechanisms located above the head. The mechanisms are driven by shafts which extend through the shielding blocks to motors located on the outside. Over the head of the vessel is a metal enclosure which is filled with metal punchings and gravel to provide shielding. A top shield cap rests on the shielding blocks.

The core structure (Fig. 3) has provisions for 60 fuel assemblies and 9 control rods of which 5 are cruciform rods and 4 are Tee-shaped rods. The present core has 40 fuel elements located in the positions (designated with R) and is controlled by 5 cruciform rods of the type shown in Fig. 4.

Control rods. The control rods are made of 60-mil-thick cadmium, mechanically clad with 80 mils of aluminum. They have an over-all span of 14¼ in. and an effective length of 32 in.

Fuel. The 40 fuel assemblies are composed of 9 fuel plates each. The plates are 120 mils thick consisting of a 50-mil uranium-aluminum alloy "meat" and 35 mils of X-8001 aluminum cladding. The meat is 25.8 in. long and 3.5 in. wide. The water gaps between fuel plates are 310 mils. The initial loading of the 40 assembly core was highly enriched and contained 14.7 kg U^{235}.

Burnable poison. On the 16 fuel assemblies in the center of the core, a full-length burnable-poison strip was spot-welded to one side plate, and a half-length strip was added to the other side plate. The balance of the fuel elements had full-length plates only on one side plate. The strips were aluminum-nickel, containing B^{10}. The half-length strips were 21-mil thick, and the full-length strips, 26-mil thick. The core contained a total of 23 gm of B^{10} as burnable poison.

Reactivity. In the design of the first core the fuel was calculated to provide about 15% excess reactivity. The burnable poison was calculated to provide negative reactivity of 11.2%. Reactivity of about 10% would be burned out in 4½ yr at normal power operation. The fission products were expected to provide additional negative reactivity of up to 2% over core life. The combined excess reactivity (or the reactivity held down by the rods) was calculated to be 3% at beginning of life, rise to over 3½% in just under one year, then start downward for a calculated life of over 3 yr at average power (see Fig. 5).

At the time of the incident, the SL-1 had been in operation for over 2 yr. The reactor had produced 931.5 Mwd of thermal energy which is approximately 40% of the design life of the core.

The Accident

On December 23, 1960, the reactor was shut down for routine maintenance, instrument calibration, installation of auxiliary system valves, minor plant modifications and installation of flux wires in the core. During the period December 27–30, 1960, the maintenance, calibration and modification work was performed. Work on the installation of the flux wires started after midnight on the morning of January 3, 1961. This work involved moving the shielding block back from the reactor, raising the water level to the top of the reactor vessel, removing all but one of the control-rod drive mechanisms and inserting the 44 flux wires into selected water channels within the fuel assemblies. The flux wires were aluminum, with sections of cobalt-aluminum alloy, and were to be used to measure power distributions within the core as part of some investigations

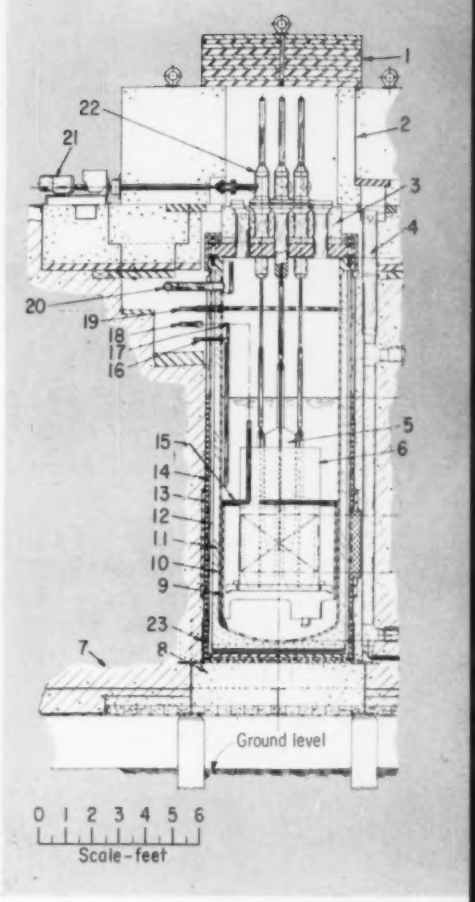
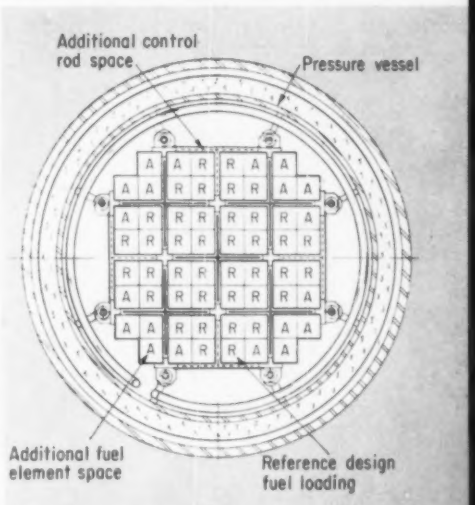


FIG. 2. SL-1 REACTOR. 1-top shield, 2-concrete shield, 3-dry shield, 4-instrument well, 5-control rod, 6-core structure, 7-gravel, 8-dry shield, 9-thermal shield, 10-pressure vessel, 11-insulation, 12-air space, 13-support cylinder, 14-lead thermal shield and cooling coils, 15-feedwater spray ring, 16-separator return line, 17-purification purge line, 18-feedwater inlet, 19-boron spray ring, 20-steam line, 21-control-rod-drive motor, 22-control-rod drive, 23-boral shield.

FIG. 3. REACTOR CORE. Normal 40-element, 5-control-rod loading is designated R; additional spaces A, permit up to 60 elements, 9 rods



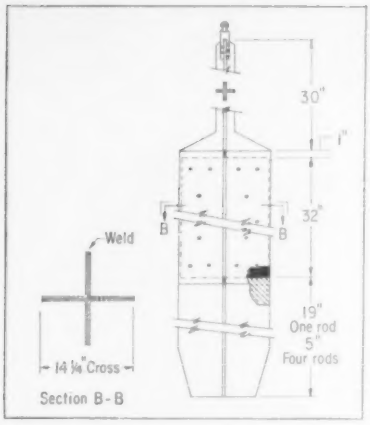


FIG. 4. CRUCIFORM RODS, five in all, controlled the SL-1 reactor. Poison was 60 mils of cadmium clad with aluminum-nickel-alloy sheets

on reactor stability.

By 4 p.m. on January 3, 1961, the installation of the flux wires was completed. The three-man, 4–12 shift on January 3, 1961, was directed to pump the water down, reassemble the control rods, install the plugs and replace the shield blocks. The next shift was to connect the rod-drive motors in preparation for resuming operations the following morning.

The incident occurred at 9:01 p.m. on January 3, 1961. Since the information that has been released covers the operations for recovery of the bodies quite completely [see AEC press release D-9, January 12, 1961], I would prefer not to repeat it and go directly to what we know, and in most cases do not yet know, about reactor and plant.

The control-room log book contains a single entry by the 4–12 shift which says "Pumped reactor water to contaminated water tank until water-level recorder came on scale. Indicates plus 5 feet. Replacing plugs, thimbles, etc., to all rods." Presumably, after this entry, the writer returned to the operating floor, and the men were engaged in replacement of the control drive mechanisms when the incident occurred.

For the insertion of the flux wires, the pressure-vessel head and the control-drive-mechanism nozzles were left in place. The control-rod extension shafts with the racks were left connected to the control rods. All of the other equipment including the shield plug was removed. This allows access through the control-rod nozzles for insertion of the flux wires. The steps for reassembly, given in detail on p. 67, are, briefly: insertion of the shield plugs, then installation of the pinion support and spring housing, connection of the rack to the mechanism, installation of the "bell housing" and finally the installation of the seal assembly.

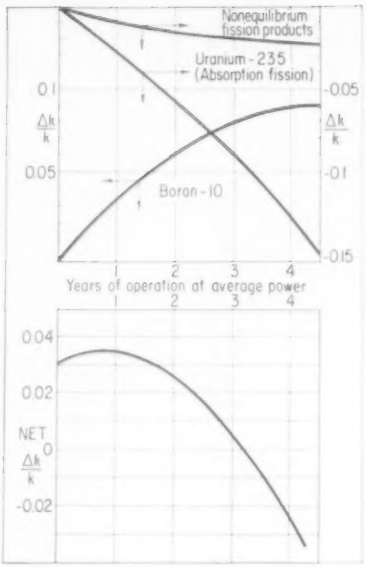


FIG. 5. REACTIVITY BALANCE among burned-up fuel, boron-10 poison and fission products (top) was expected to lead to excess-reactivity curve shown at bottom for 3-yr design life. Compare Fig. B, p. 68

During the shutdown, the mechanisms were removed from positions 1, 3, 4, 7 and 9; the control drive mechanism was left in place on position 5. A dummy mechanism was being used on position 4 for testing a new type seal. Capped shield plugs had been removed

Board Sees Central-Rod Movement as Most Likely Cause

"It appears now that the most likely immediate cause (of the SL-1 accident) involved some movement of the central control rod." This is the most significant statement in the Interim Report by the five-man SL-1 Board of Investigation.

The report disclosed that the control rods in SL-1 had a history of sticking and difficult operation: "From early operations onward, intermittent and increasing difficulty was encountered in the free movement of the control rods . . . It was frequently found that one or another of the rods would not fall freely in a scram . . . Later the rod-sticking problem, both on insertion and on withdrawal became accentuated . . . Over the last two months of operation, approximately 40 rod stickings were recorded . . . During the last period of reactor operation, the rods were assisted manually in their withdrawal, and on scram at shutdown, three rods had to be driven in by their motors."

As to possible causes, the report says it's "possible to conceive of several different items or combination of items which may have constituted the immediate initiating event. The accident could have occurred with no errors on the part of the crew being committed, though certain errors on the part of operators also can be visualized as possible initiating events." Among them: 1. Raising the central control rod excessively. The job the men were assigned to do—reassembling the control rod drives—involved lifting the control blade a maximum of 4 in.; the chief operator and operator on duty (third was a trainee) had been specifically trained for this job, had done it at least four times earlier, and had been explicitly instructed that "under no conditions was the central control rod to be lifted more than 4 in." In the light of the most recent measurements prior to shutdown on Dec. 23, 1960, the central rod would have had to be raised at least 16 in. for criticality, and, it's estimated, a further 6–8 in. in $\frac{1}{4}$ to $\frac{1}{3}$ sec to produce an excursion such as took place. These actions and conditions are termed "credible" but "not probable." 2. Changes in the properties of the reactor may have occurred between Dec. 23 and Jan. 3 to reduce shutdown margin of reactivity, so that substantially less withdrawal of the central rod would have produced criticality. "There is no evidence at present that any such changes took place."

from positions 2 and 6. There was a stainless-steel cap on number 8 and the cap was in place on the water-level and neutron-source opening.

Post-Accident Evidence

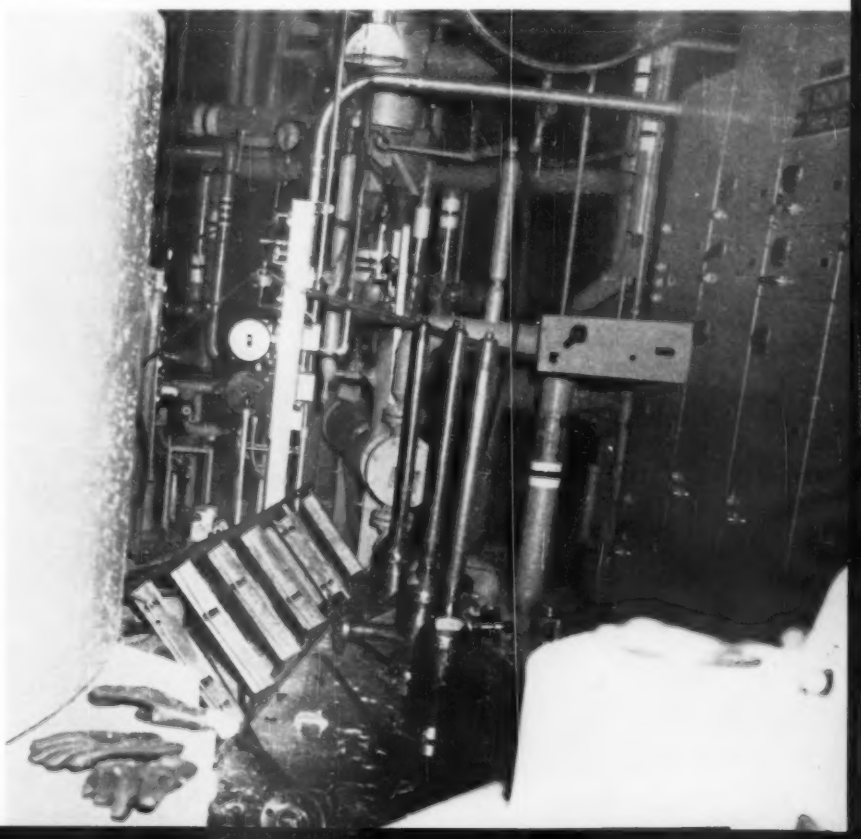
A photograph of the reactor head area taken late on Saturday, Jan. 7, four days after the incident, shows the following (Fig. 6):

- The metal cover of the pressure-vessel-head dry shield has been forced upward and cylindrical metal punchings and gravel have been forced out covering the floor area in the foreground.
- Control drive 5, which had not been removed during the shutdown, remains in place.
- The racks are protruding from nozzles 1 and 7 and are about 6 in. further out than they would normally be during a shutdown. The threaded end of the rack in 1 is broken off, and the end of the rack in 7 is in place although it cannot be determined whether the threads are stripped.
- Across the top of the head is a shield plug believed to be from position 4, and the flange on this plug is bent. A portion of the extension shaft is still in this plug. There is an object alongside this plug which might be either part of another extension shaft or a handling tool.
- The racks normally protrude from the openings about a foot, but there is no evidence of the racks in positions 3 and 9.
- The capped shield plug on 2 is in place. A cap had been in place on 8. It is thought that this cap would not have been removed by the crew and it is felt that it was blown off during the incident. The end of the studs appear to indicate that the cap nuts may have sheared off.

In the next photograph (Fig. 7), the first taken of the accident, the "bell housings" are stored in a normal position for a maintenance operation. Three are clearly visible, and on close inspection you can see the top of a fourth housing which is sitting behind the middle one. In the foreground are seal housings, and in very clear photographs it is felt the flange of a fifth bell housing laying behind the shield plug can be seen. This would account for all six housings. None of the shield plugs are shown in this photograph, and the assumption is that all of the plugs had been replaced on the reactor prior to the incident.

FIG. 6. AFTER THE ACCIDENT control-rod-drive area shows effects of explosion (read details in text, left) while panel meters in background are undamaged. Pressure-vessel penetrations are in three rows of three. Penetrations in nearest row (between shield blocks) are numbered (from left to right) 2, 1 and 8; next row back is 3, 9, 7; last row is 4, 5, 6. See p. 30 for important new photograph of this area

FIG. 7. FIRST POST-ACCIDENT PHOTOGRAPH was taken two days after accident (and two days before the one above); ladder was knocked over in post-accident period. For orientation, shield block at left is one at left of Fig. 6. For discussion see text, left



From examination of the bodies, it has been postulated that their injuries are such that two men could have been carrying a bell housing (presumably the one that is on its side in Fig. 7) and the third was working on top of the reactor.

In addition to the information shown on these photographs, other observations have been made relative to the effects of the incident:

Two additional plugs were located in the ceiling over the reactor. From the position of these plugs, it is assumed that they came from positions 1 and 7. Also, there is a hole in the fan floor over the reactor and it is assumed that one and possibly two plugs penetrated the fan floor. If this is the case, it would account for all of the plugs.

The physical damage is confined to the area directly above the reactor. Tools lying on the shielding blocks appear to be unmoved, and only the lightbulb directly above the reactor is broken.

There is some indication of water markings on the ceiling and some of the gravel adjacent to the reactor has a washed appearance. It was possible for water in the reactor room to drain back into the gravel shielding surrounding the reactor. Also, it appears that water came out of the loading doors.

Radiation Levels

As has been reported, the levels of activity within the operating room are 500–1,000 r/hr. These levels are in the area around the shield plugs, and some of the levels out at the building walls are 100 r/hr.

The levels of activity around the site on January 7, 1961, are as follows: 7 r/hr at the base of the building, 3.5 r/hr at the foot of the stairs, 1.15 r/hr in the control room, 0.5 r/hr in the support building, 0.25 r/hr at the road into the site [for map of radiation levels see NU, Feb. '61, p. 19].

The levels within the operating room and around the site have remained at near the same levels since the incident. Early the morning after the incident, aerial checks for airborne contamination were made but no indication of activity being dispersed from the site was found.

The results from samples taken within the reactor building that have been analyzed are as follows:

1. Bare gold foils from a Hurst dosimeter that was located near the entrance to the operating floor indicate a neutron exposure of 1.2×10^8 thermal neutrons per cm^2. Cadmium-covered gold foils and sulfur pellets were also activated, but the resulting data have not been analyzed.

2. A brass screw taken from a cigarette lighter indicated a neutron exposure of 9.3×10^9 thermal neutrons per cm^2.

3. A brass watchband buckle indicated a neutron exposure of 1.8×10^{10} thermal neutrons per cm^2.

4. Gold jewelry indicated a neutron exposure of 9×10^9 thermal neutrons per cm^2.

5. A recent analysis of a stainless-steel gasket retrieved from the reactor room shows Co^{58} activity produced by the Ni^{58} (n,p) Co^{58} reaction with threshold at 4 Mev, indicating a fast-neutron exposure of 2.5×10^{11} fast neutrons/cm^2.

6. Analysis of samples taken from the clothing of the victims has shown the presence of uranium and strontium-91. Quantitative analysis of these samples yields a yttrium-91 activity of 2.4×10^4 dpm/ml.

7. Soil samples from within the area, clothing samples from personnel that have entered the reactor room, and air samples from the control room have all shown a gross fission product spectrum.

8. A Hurst dosimeter, with a minimum detection level of less than 10^3 neutrons/cm^2, inserted by means of a crane boom on January 8, 1961, indicated no neutron activity.

9. Iodine activity surveys were made at the control point which is ¾ mile from the SL-1 and at Atomic City which is 5.3 miles south of the SL-1 site. On the night of January 3, and on January 4, measurements showed I^{131} concentrations to be less than 10^{-9} μc/ml at Atomic City. On January 14–16 the concentrations were: Control point, 6×10^{-10} μc/ml; Atomic City, 3.5×10^{-11} μc/ml. On January 19–20: Control point, 1.5×10^{-10} μc/ml; Atomic City, 2×10^{-11} μc/ml.

10. Analysis of vegetation on the site indicates a total airborne release of I^{131} to be 1 curie for the time up to noon on January 4, 1960, an additional 3 curies during the following 24 hr, and 3 more curies during the next 6 days. During this period, temperature inversions averaged 17 hr per day.

Accident Analysis

From the information, we can only postulate on the cause of the incident and why certain of the effects resulted. More information and analyses are necessary before we can hope to determine the cause and the reasons for all the effects. Factors that are now considered pertinent are:

1. It is quite conclusive that there was a neutron excursion during the incident, but whether it was the initiating cause of the incident or was instituted by something else is not known.

2. The SL-1 reactor was capable of going critical with the movement of only the center rod. Further, the installation of the control-rod mechanism does involve manual movement of the rods.

3. During the maintenance operation, the control rods are held by a ball fixture resting on the core structure. It is conceivable that this connection to the rod, though it could only drop 3 in. before being stopped by the bottom of the shroud, could have broken and the rod dropped down. This would have the effect of removing a poison from the top of the core. Analysis of this must be made.

4. During the last year of operation there had been a physical loss of the boron burnable poison prior to the incident (see p. 68 for discussion of this). Action had been taken to compensate for this loss. A complete analysis of the core must be made to establish whether there could have been an unexpected loss of additional boron which could have been the cause of the incident. It is wholly conceivable that the rate of corrosion of the burnable poison increased. Although this presented no problem during operation and was possibly not even detectable, it could have resulted in a nearly complete loss of shutdown margin under the cold, no-xenon conditions present during the shutdown. It is also possible that the methods of calculations are not sufficiently exact to predict accurately the effect of the loss of burnable poison in the central portion of the core on the future shutdown margin of the central rod.

5. The SL-1 had been in operation over two years. It is possible that the effectiveness of the rods was decreasing, particularly on the lower ends. There was peaking in the center of the core due to loss of boron which would increase the irradiation of the rods. Analysis must be completed to determine whether the rods had lost suffi-

Hooking Up Control Rods—Crucial Ingredient in SL-1 Accident

In the operation that was being performed control-rod drives were being connected at the time of the accident. All of each control-rod drive except the extension shaft and the rack, with the rack and the flanged head nozzle, had been removed. In Fig. A one can see the rack protruding up through the hole, held on the lower end by its connection to the control rod and the upper head by the nozzle.

The first operation in the reassembly is to place the shield plug over the rack and lower it into the nozzle. Next, the pinion support and spring housing are lowered over the rack and bolted to the shield plug. At this point the threaded top of the rack which is shown in this drawing in a raised position, is down inside the spring housing about 3 in.

A lifting tool (Fig. C) is attached to the threaded end on the top of the rack. A crossbar is inserted and the rack and control rod are lifted 6 in. to the point that a C-clamp can be attached to hold the rod in a raised position.

Note that when the rod is disconnected it rests in a position 3 7/8 in. below the zero operating position. Therefore, the 6 in. of movement corresponds to raising the rod 2 1/8 in. above the zero operating position.

After clamping the rack the tool is removed and a washer and nut placed on the threading end of the rack. This nut and washer acts against the spring to hold the rod in the zero operating position and to absorb the force of scrams. The lifting tool is again attached and the rod lifted to free the C-clamp for removal.

This operation is normally done by two men. One lifts and the other engages and disengages the C-clamp. A strong man by gripping the tool with one hand can lift it and engage the C-clamp with the other hand. The control rod is then lowered to the spring. The pinion gear, with bearings and retainer ring, are then inserted and the completed assembly is as shown in Fig. B.

This is the point at which the bell housing is brought in and placed over the rack. Note that the studs protrude through the plug, but are not at this time bolted down. Thus at this stage pressure inside would raise the plug which in turn would carry the rod and rack with it. Next, the bell housing is placed over the mechanism and bolted in place with the 8 1/8 in. Allen-head nuts. Then the pinion coupling, stud shaft is inserted and the sealed assembly is bolted into place.

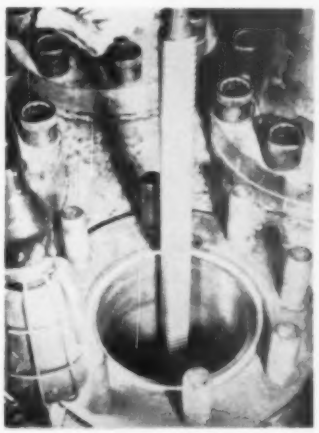


FIG. A. ASSEMBLY STARTS with rack at top of control-rod extension shaft extending about 6 in. through flanged nozzle above pressure vessel. Top of rack, cut off here, is threaded

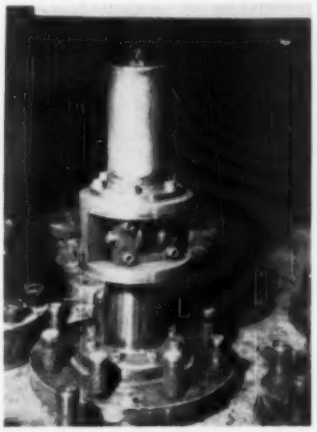


FIG. B. ASSEMBLY ENDS, save for bell housing, when shield plug and pinion housing have been slipped over rack in turn, washer and nut threaded to top of rack

FIG. C. TOOL FOR LIFTING CONTROL ROD MANUALLY threads onto screw at top of rack at right-hand end, has channel for lifting cross-bar at left-hand end

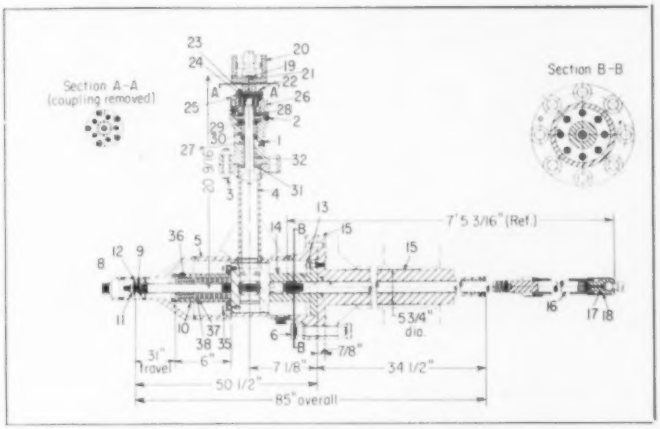


FIG. D. CONTROL-ROD DRIVE ASSEMBLY is shown here on side. Rack is labeled 20; shield plug is 15; bell housing is 5

cient worth to change the critical position.

6. Since only the center rod could take the core critical by itself, it will be extremely important to determine whether the center rod was being worked on at the time of the incident. We hope to do this by finding all of the mechanism parts and the tools. In this regard, it is difficult to explain why the threaded end is broken off control rod 1 and not off rod 7. Only under extreme acceleration or by eccentric loading would one expect failure at this point.

Another important item is the condition of the reactor with respect to internal pressure during the time of the control rod replacement. During the replacement of the mechanism the shield plugs are first inserted. These plugs are securely set in place. These plugs are not bolted down until the "bell housings" are put into place and the same bolts connect both the "bell housings" and the shield plugs to the nozzle flanges. In the control drive assembly procedure (see p. 67), after the nut is put on the threaded end of the rack, any upward motion of the shield plug will raise the rod. Further, in normal sequence of control-drive installation, all of the shield plugs are put in place and the racks are connected before any of the bell housings are bolted into place. The shield plugs are a relatively snug fit and have a cross-section area of about 27 in. each. Since the control rods, extension shafts, rack and the plugs have a combined weight of about 225 lb, it means a pressure of less than 10 psig in the steam space would suffice to raise all of the rods connected to the plugs.

What could create a pressure in this space when the reactor was shut down? The core of the SL-1 has been in operation over 2 yr, and gamma activity from the fission products would cause disassociation of the water and generate 2 to 20 liters of hydrogen per hour. The evolved hydrogen conceivably could have created an explosive mix-

Pre-Accident SL-1 Report Reveals Serious Boron Corrosion

One of the major points in Dr. Pittman's presentation was the problem of the corrosion (and erosion) of burnable-poison strips (boron-10 in aluminum-nickel alloy) that were included with the original SL-1 fuel elements to compensate for the excess reactivity of the enriched uranium in the core; these permit a longer core life—as the uranium burns out so does the boron. We present here some of his slides but elected to use the commentary from a report on the subject dated September 30, 1960.

"Loss of the burnable boron poison from the SL-1 Core 1 by corrosion may lead to an unsafe operating condition," begins the summary of CEND-1005, "Evaluation of the Loss of Boron in the SL-1 Core" by C. W. Luke and H. Cahn of Combustion Engineering Nuclear Division. "Results indicate approximately an 18% loss of the boron from the core, which is equivalent to a 2% $\Delta k/k$ gain in reactivity. The reactor has an adequate shutdown margin of approximately 2% $\Delta k/k$ at the present time. Remedial action to replace the lost boron is required.

"It is recommended that poison in the form of 60-mil cadmium strips be placed in the T-rod slots in order to return the rod bank to the predicted level. No restrictions should be put on operating power because of the loss of boron." Thus concludes the summary in CEND-1005. [Six cadmium strips were placed in two of the T-rod slots on Nov. 15, 1960; this added 1% in negative reactivity. See Fig. B.]

Within the report are found more details on measurements and

FIG. A. WARPED CONDITION of burnable-poison side plates is evident in this photograph. Since plate is tacked (at three points) a cross width as well as along length surface is dimpled rather than corrugated as might appear from this view. Warping made fuel-element removal difficult; forced removal contributed to plate defects shown in Figs. C and D

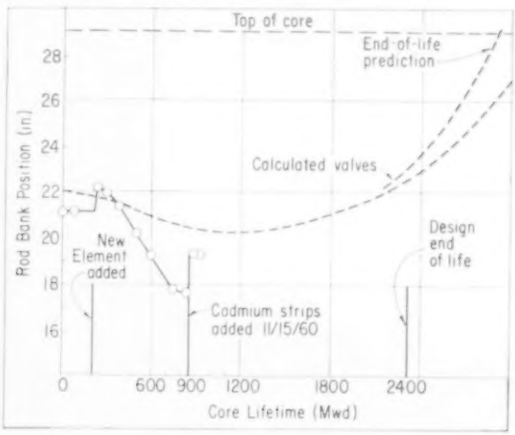


FIG. B. BORON CORROSION ATE UP 2% in shutdown margin as reflected in control-rod-bank position for criticality (solid curve). Loss of boron accounts for progressively more fully withdrawn rod position for criticality starting at about 300 Mwd, but suppressed zero on ordinates exaggerates the effect. Addition of cadmium strip on 11/15/60 helped some

ture in the steam space. Very preliminary results from our calculations indicate that the pressures that could have resulted from ignition of hydrogen would not be high enough to cause the damage observed, such as the forceful ejection of the plugs, the distortion of the head, or breaking the cap from the number 8 nozzle. However, this pressure would raise the plugs with the control rods and result in the insertion of a large amount of excess reactivity in a short time.

Another possible explanation would be steam pressure. Even if the reactor was accidently taken even a small amount over critical, steam would be produced which could act against the plugs and start ejection of all the rods.

We have considered the possibility of an aluminum-water reaction, but since the temperatures of the reactor were low, it seems highly improbable that such a reaction could have produced the initial pressure.

Effects of the Accident

In closing I would like to note a few items relative to the effects of the incident:

The yttrium-91 analysis of 2.5×10^4 dp/m/ml corrected to the time of the incident indicates that 1.5×10^{18} fissions were involved in the incident. This corresponds to approximately 50 Mw-sec of nuclear energy. [As a point of reference the Borax-1 excursion of 1954 was 135 Mw-sec.] This would correspond to about 16 sec of operation at normal power level of 3 Mw.

Based on the damage to the cover plate over the head, the assumption that the cap on nozzle 8 was blown off, and the fact that damage was confined to a localized area above the core, it appears that water was expelled rather than steam. It is quite probable that several of the rods are still out of the core, but all indications since the incident indicate that the core is no longer critical. The mechanism of core shutdown is not yet known; possibly it was by expulsion of water. We are now in the process of installing instrumentation to monitor the core in preparation for positively shutting down the core.

A rough calculation based on SL-1 operating history indicates that the core at the time of the incident contained about 1,000,000 curies of fission products. The samples from the operating floor that have been analyzed contain uranium and fission products and are certainly from the core. However, if the activity on the operating floor was assumed to be solely due to uniform contamination with core fission products, it would be much less than 1% of the fission products that were in the core. However, we do not yet have detailed information on the concentration of activity in the operating room.

On one previous occasion, 11 in. of the core were exposed. At that time the activity levels on the operating floor were 100–200 mr and the activity directly over the core was 1,000 r. It may be that an exposed core is now the principal source of the activity and is the reason that no appreciable decay has been noted.

Even though the SL-1 building is not a containment shell, it appears that practically all of the particulate fission products have been confined to the operating floor and to the immediate area surrounding the power plant building. The airborne activity level at the control point, ¾ miles from the plant, on January 14–16, 1961, showed an iodine level of ½ the maximum permissible concentration for a 168-hr week. On January 19–20, 1961, the levels were $\frac{1}{50}$ of maximum tolerances. There is some indication that airborne activity is still being released since these levels have not been reducing more rapidly.

calculations "accomplished during the month of September, 1960" that support the summary—in particular the "shutdown requirements in case of a complete loss of boron" are calculated. The conclusion: " . . . should there be a total loss of boron at the present time, the reactor, cold with all rods inserted, would be supercritical by a value of 3.3%."

CEND-1005 also gives, in Appendix B, the contents of a Data Report on test T-2.1—Visual Fuel Element Inspection: "The fuel assemblies were visually inspected for corrosion, indication of fuel plate swelling and corrosion of the boron plates. The test as originally conceived included the inspection of five fuel elements. The test was terminated after three elements were examined because the corrosion of the boron side plates was found to be so severe that further removal of elements with the resultant disruption of the boron can cause an unsafe condition in the reactor . . . Results indicate that corrosion or film burnup in the (fuel) elements has not appreciably decreased from the last inspection. However, severe corrosion of the boron side plates had taken place. It is recommended that this test be limited to a final examination at the end of core life.

"Removal of all elements was difficult. The previously reported expansions of the boron side plates appeared to have increased. As each fuel element was removed from the core, a cloud of reddish material, believed to be iron oxide, and a light flocculent material formed about the elements."

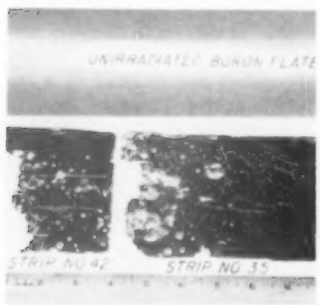


FIG. C. CONSIDERABLE CORROSION is evident in this comparison with fresh plate, top, with two side plates dislodged in the course of fuel-element examination

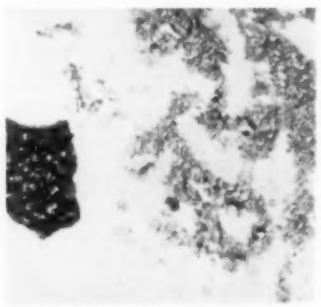


FIG. D. BORON-PLATE DEBRIS was vacuumed from bottom of pressure vessel after examination described above, 18% of boron was estimated lost as of Sept. 30

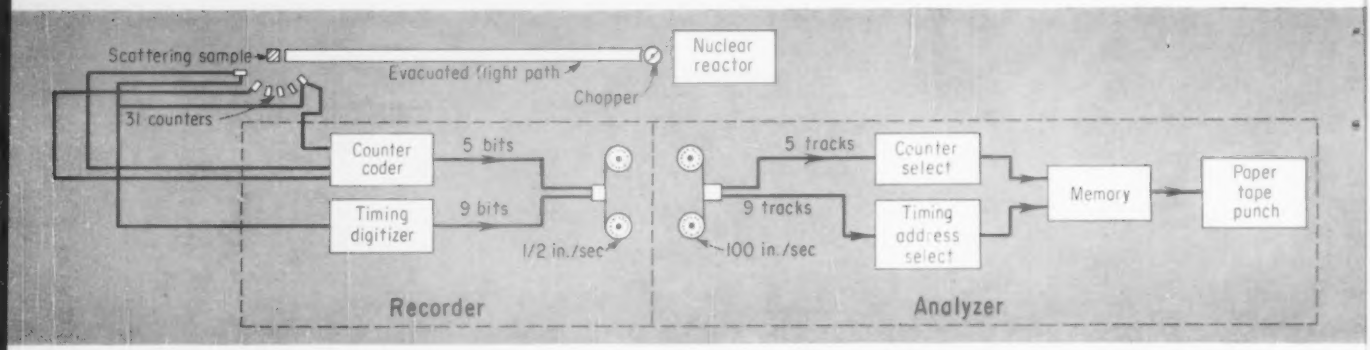


FIG. 1. NEUTRON SCATTERING EXPERIMENT has chopper to produce bunches of reactor neutrons traveling down evacuated flight path. Pulses from 31 counters around scatterer go in parallel to writing heads; separate signals identify counters

Digital Magnetic Recording Speeds Nuclear Experiments

If you use magnetic tape to record nuclear events as they occur, analyze each tape 32 times at 10–100 times recording speed, you get 32 times as much information in about the same time

By JOHN R. WATERS* and J. ROGER BIRD, *Atomic Energy Research Establishment, Harwell, England*

THE INCREASING COMPLEXITY of nuclear-physics experiments requires that methods used to record and handle data be the most refined that are possible. A magnetic-tape data-handling system was developed at Harwell chiefly to fill the needs of neutron-physics groups for many time-of-flight-analysis channels. It has proved adaptable to many other types of experiments as well.

Among many successes of the system are these:

- recording time of flight of neutrons as they are detected by a number of counters
- recording gamma-ray spectra after neutron capture as a function of both neutron and gamma-ray energy
- recording the results of three-dimensional pulse-height analysis (two pulse heights).

Our basic technique is to record a 16-bit binary word across a 1-in. magnetic tape—each word carrying coded information describing one event seen by the detectors. Several related pieces of information can be combined in one 16-bit word, and this combination leads to great flexibility in the types of data that can be recorded. The recorded information is played back into a 1,023-channel analyzer. Many replays are necessary to extract all the information from the tape, but, since the analysis is done at 10–100 times the recording speed, this replaying is not objectionable. Using several recorders with one analyzer leads to a large saving in cost of the whole installation.

RECORDING SYSTEM

Our present system grew from digital tape recording of a nuclear physics experiment—an investigation of low-energy neutron scattering from a moderator as a function of energy and angle (Fig. 1) (*1*, *2*). Bunches of neutrons produced by a chopper pass down an evacuated flight path to strike the moderator. Counters arranged around the moderator detect scattered neutrons; since small counting rates were expected, 31 counters, at various angles, were used. Signals from the counters were put in parallel and recorded on tape along with a number that identified the counter that supplied the signal. On analysis, signals were separated, and collected data were fed into a computer from a punched paper tape.

Since this system (designed and built by E.M.I. Ltd., Hayes, England) appeared very promising, new recorders were designed by F. H. Wells, J. G. Page and J. R. Waters for use with other neutron experiments. The neutron source at Harwell has been designed so that neutron physicists there can perform ten or more experiments at the same time using different flight paths. Since each experiment would need a several-hundred-channel analyzer for

* PRESENT ADDRESS: Palmer Physical Laboratory, Princeton Univ., Princeton, N. J.

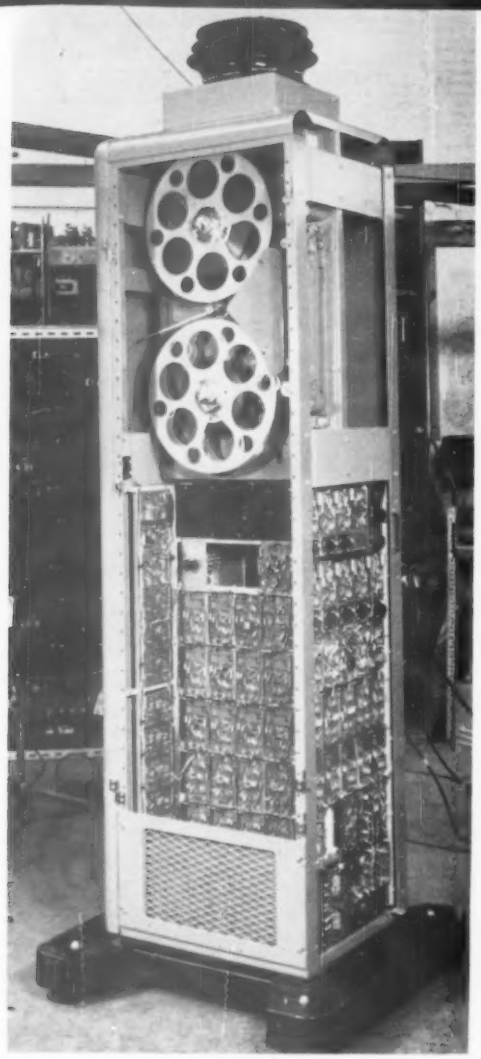


FIG. 2. GENERAL-PURPOSE RECORDER at AERE has transistor circuits, slow tape deck and air-tight doors (removed)

either time-of-flight or pulse-height work, the amount of electronics would be enormous. Tape recorders have proved particularly valuable in this situation, and this usefulness has been one of the main influences in speeding their development and use. Since the recorders contain a program panel that allows them to be set up for a different kind of experiment merely by altering plug-in jumper wires, they are truly general-purpose instruments.

Recorder

The purpose of the recorder is to write experimental information in digital form onto magnetic tape so that it can be read later by an analyzer. It consists of an inexpensive tape transport for 1-in-wide tape, which can be driven at either 1 in/sec or 2 in/sec, and its associated electronics. Sixteen parallel tracks are written on the tape, the maximum pulse-packing density being 200 ppi (pulses per inch) on each track. Writing across the tape, rather than serially, keeps writing time as short as possible. Coding is done by analog-to-digital converters (digitizers). Since the information is, in general, arriving at random times, there are gaps between recorded words. At 1-in/sec tape speed it would be possible to write up to 200 words/sec if the information arrived at regular intervals.

The tape transports can handle 14-in-diameter reels that hold 7,200 ft of thin-base instrumentation-grade magnetic tape. This provides 24 hr of recording time at 1 in/sec yet takes but 15 min for one pass on the analyzer.

Figure 2 shows the recorder with dust-tight doors removed. The electronics uses transistors and printed circuit boards.

Since as many as six recorders may be used in conjunction with one analyzer and all recording heads must be carefully aligned, we have made provision for small adjustments of the heads for tilt and position across the tape.

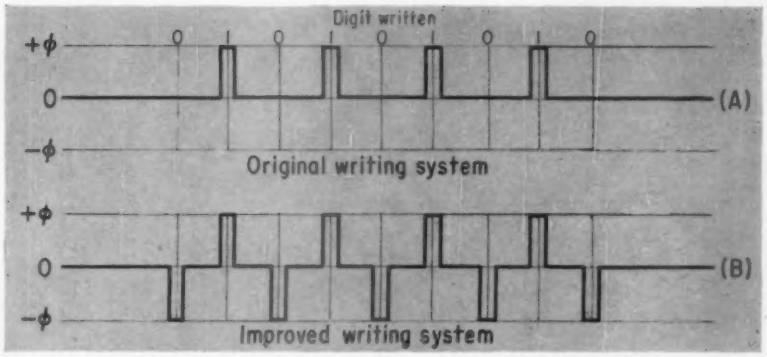


FIG. 3. TWO WRITING SYSTEMS. Original one (A) wrote "1" as magnetized bit left "0" blank. Present one (B) writes "1" as positive magnetization, "0" as negative

Writing Methods

Writing circuits are provided to energize the heads when they are triggered by a pulse. Originally these circuits were designed to write a pulse on the tape for a "1" and leave it clean for a "0" (Fig. 3A). This method of writing was found to be unsatisfactory, however, since imperfections in the tape introduce errors by causing "drop-outs," signals missed on playback because they are not of full amplitude. If such a drop-out occurs, a track that should be read as a "1" appears to have a "0." This original method is unsuitable when accuracies greater than 1% are required. For greater accuracy drop-outs must be detected and the corresponding word rejected. Check digits could be used for this purpose, but these would use extra tracks on the tape; instead we changed our recording system so that a "1" was represented by a positive pulse and a "0" by a negative one (Fig. 3B) (3). The absence of a digit can then be detected by looking for a multiple coincidence among all recorded tracks and rejecting any words that do not have 16-fold coincidence. The number of rejected words can be counted in a scaler to give a continuous check on the performance of the system.

Our method of recording differs from the two most frequently used in computer work, return-to-zero (RZ) and non-return-to-zero (NRZ) (4). We did not feel that either of these methods was better than the one we used. Moreover our method has the great advantage that drop-outs can be easily detected and their frequency noted. Also our method has the advantage of simplicity when the recording is being done on a clean tape. (In computer work the tape usually contains old information so that one can not use the state of zero magnetization to convey information.)

Recording Rate

The tape recorder systems that have been described are limited to fairly low-counting-rate experiments by the long time required to write on the tape. At 1 in/sec and a pulse-packing density of 200 ppi this is 5 msec. Thus if 1% counting losses are acceptable, a mean random rate of 2 cps can be accepted. This rate is rather small for many nuclear-physics experi-

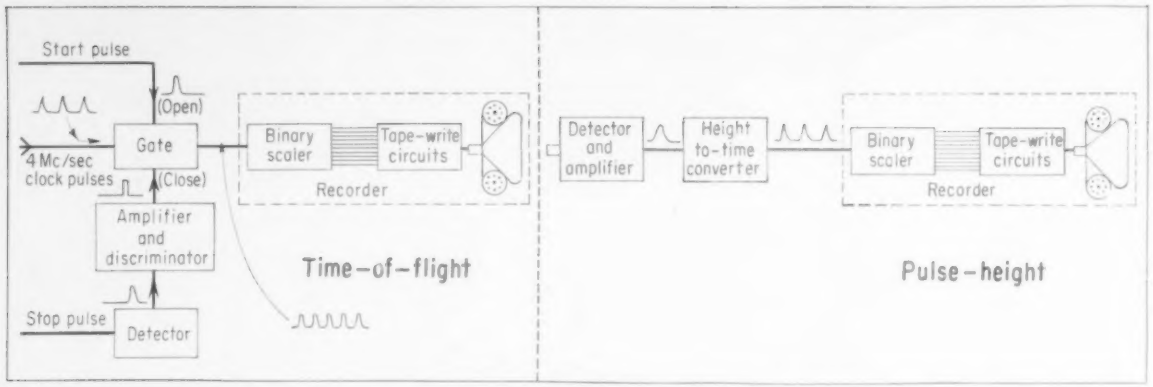


FIG. 4. ANALOG–TO–DIGITAL CONVERSION of time of flight (left) uses gate that opens at time zero, admits pulses until gate closes. Height–to–time converter produces pulse train proportional in length to scintillation amplitude

ments. There are three ways in which one can adapt the recorders to accept greater rates:

Tape speed. The obvious way to make recording fast is to run the tape faster. By going to 10–20 in/sec a corresponding increase can be obtained in the recording rate but at the loss of recording time per reel. At 15 in/sec there will be a 1½-hr recording time and the possibility of 1.7×10^5 pulses on a reel at 30 cps (1% losses still).

Pulse density. The second way is to increase pulse-packing density on the tape. This might be done by going to a different writing method—non-return-to-zero for example—and a precision tape transport. We feel that with 1-in. tape the difficulties of preventing tape from skewing as it runs past the magnetic heads would limit the pulse-packing density to at most 500 ppi.

What We Can Record

Pulse heights Time of flight Time delays	Up to 32,000 channels in several groups at the same time.
Counter number Target number Beam position	256 or more (can be set by automatic sample changer)
Coincidence Anticoincidence	"Yes" or "no" in several counters
Voltage Current Magnetic field	In digital form
Counting rates Monitor counters Backgrounds	Rates limited only by speed of auxiliary scalers

Derandomizing. The best way to increase the acceptable pulse rate is by derandomizing the input information. If this can be done, input rate can be matched to recording rate.

A derandomizer (*5*) consists of a small-capacity fast-memory device that can store information rapidly with a short dead time and read it out at a regular rate. Wells and Page have designed one for data handling at Harwell. It consists of a parallel-entry six-word (16-bit/word) ferrite-core memory with associated driving circuits. Dead time is a few microseconds. A capacity of five or six words is all that is needed. Such a six-word store allows the average random counting rate to be increased by a factor of 75 with 1% counting losses (*5*). At 15 in/sec the random rate now acceptable is 2,250 cps and there can be 13×10^6 counts on a reel. At this rate the dead time of conventional pulse-height digitizers (~80 μsec) begins to affect counting losses.

Impulsed transport. For small-counting-rate experiments, as for example when multiple coincidences are required, the counting rate may be so small that the smallest tape speed available is still uneconomical. Hence it becomes wasteful to keep the tape recorder running continuously. One can use an impulsed digital transport that can start and stop in a few milliseconds, the tape being moved $\frac{1}{200}$ in. after each recorded pulse so that there is no overlap.

An advantage of the derandomizer and the impulsed tape deck is that they increase the amount of information that can be recorded on a given length of tape. With a constant-speed recording deck there might be pulses on only 1%–2% of the tape because of the randomness of the incoming information in time. By derandomizing the information and matching tape speed to mean counting rate, this can be increased to about 70% with a corresponding decrease in the length of tape used. This reduces analysis time and is of great importance when a reel of tape has to be analyzed 32 times to extract all its information.

Analog–Digital Converters

Since the recorder is designed to write a binary number on tape, incom-

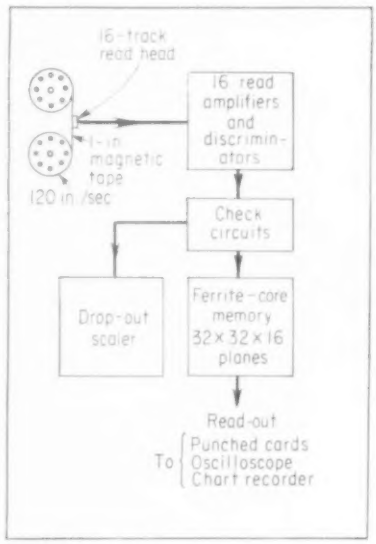


FIG. 5. ANALYZER selects words of interest, checks for dropped digits, counts acceptable words in ferrite memory

ing information, which is in analog form, must be put through an analog-to-digital converter (sometimes called a "digitizer"). These units have different forms for the several types of information as shown in Fig. 4.

For time-of-flight data, the digitizer consists of a gate circuit. This is opened by a "start" pulse at a fixed time after time zero (when accelerator fires or neutron chopper opens) and allows a continuous train of pulses through it into another scaler. When the neutron signal arrives it closes the gate, stopping the count in the scaler.

As a time-of-flight analyzer, the original tape recorders gave as many as 4,095 channels of ¼-μsec width. This was an arbitrary limit; the maximum number of channels available is $2^{15} = 32{,}768$ (one of 16 tracks is reserved as a clock track), and in later-model recorders the channel width has been reduced to ⅛ μsec.

For pulse-height data, the digitizer is the usual Wilkinson amplitude-to-time converter used in multichannel pulse-height analyzers. This converts the pulse height into a train of pulses proportional in number to the pulse height. This train of pulses is then counted in a binary scaler in the recorder, and the resulting binary number is written on the tape. With sodium-iodide scintillation counters 128 channels are most frequently used in pulse-height work although 256 or more could be used if required.

The table on Page 72 is a summary of the types of information that can be recorded with our present system.

ANALYZER

Recorded tapes are replayed on the analyzer which is, in effect, a small computer with rapid data transfer—in and out—and very simple mathematical ability. It contains a fast tape deck (100 in/sec), decoding circuitry, a 10-bit ferrite-core memory and read-out and display devices as shown in Fig. 5. Words read from the tape are stored in the memory in the correct address until the whole tape has been run through. Thus the analyzer adds up the number of times that each word (any particular combination of experimental data) has been written on the tape. It can display the totals on punched paper tape for transfer to a general-purpose digital computer for further analysis.

The analyzer uses standard plug-in

Data Points in Three Dimensions

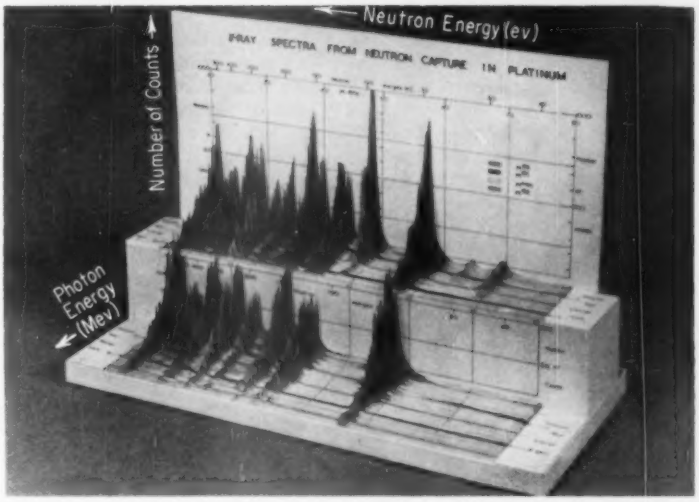


FIG. A. GAMMA PHOTONS FROM NEUTRON CAPTURE in platinum appear in three dimensions (neutron energy, photon energy, counting rate) by stacking 63 graphs of counting rate as function of neutron energy (10). Separations along photon-energy scale are 70 kev, and data should be smoothed from one graph to next. Model represents 16,384 data points. Step shows position of scale change by factor of five. Twenty neutron resonances appear as sudden increases of counting rate as one moves in direction of increasing neutron energy (47, 54, 68.5, 98 ev). Shapes of resonances in direction of increasing gamma energy vary because different resonances occur in different isotopes. Thus 98-ev resonance in Pt^{198} target falls away more rapidly than 68.5-ev resonance in Pt^{196} target because binding energies of product nuclides are different

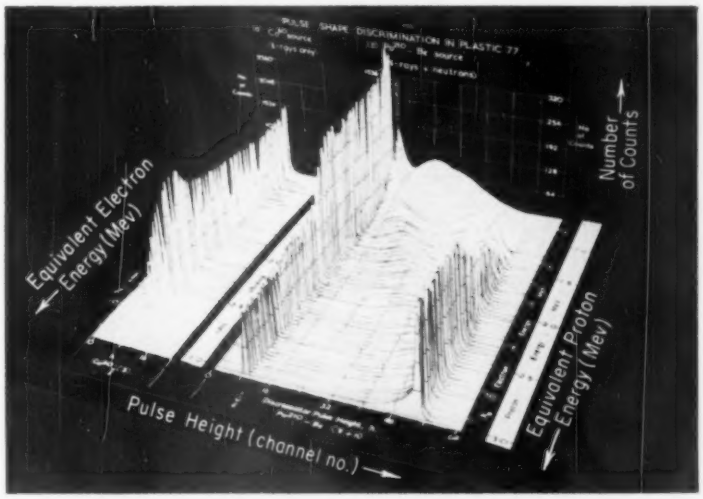


FIG. B. PULSE-SHAPE SPECTRUM IN PLASTIC shows counting rate as function of two different pulse heights (8, 11). Axis across back (h) is pulse-shape coordinate, small for quick decay and large for long decay. Axis from back to front is total-light-in-pulse coordinate, proportional to particle energy. It is scaled in two sets of units: equivalent energy for Compton electrons scattered by photons (white on black) and equivalent energy for protons recoiling from neutrons (black on white). Two sections of model show responses to Co^{60} gammas only (left) and Po-Be gammas and neutrons together. In both sections gamma pulses accumulate in Channel 9 of h scale. Neutron pulses appear in two ridges that converge to Channel 54 of h scale for large h_0. Other scintillators (for example, stilbene) show only one neutron ridge instead of two

Paper Tape, Punched Cards—How Do They Compare?

Our methods are not the only ones that have been used for storage of experimental data. Information can be punched into paper tape and cards (12, 18). They can also be stored in magnetic tape with systems quite different from ours.

The main difficulty with punched paper tape and cards is that standard tape and card punches are rather slow and prone to the faults of such mechanical devices. Of the two, tape punching is faster, the standard speed being sixty 5- to 8-digit characters/sec. This is about 1/10 the speed of our slower tape recorder. Faster tape punches of 300 characters/sec are currently available. Paper tape can be read at 500 characters/sec so that paper-tape storage could feed into a small computer.

Digital recording is just one way of using magnetic tape for the storage of data. Halfhill (4) has discussed the various other possibilities—pulse-duration modulation (PDM), frequency modulation (FM) and direct analog recording. In PDM, pulses of varying amplitude are converted to constant-amplitude pulses of varying width. PDM systems have an accuracy of ~1% for the complete data system, relatively independent of tape-speed variation. In FM systems accuracy is about the same as for PDM, but the system is not so suitable for pulse recording.

Analog Recording

Cavanagh and Boyce (13) showed that one can record pulses directly on tape in analog form, the recording current through the head being proportional to the input pulse voltage. The tape was replayed on the same tape transport but at a faster rate, the recorded pulses being fed into a multichannel pulse-height analyzer to obtain their spectrum. The advantages of this system are that data are in permanent form, the time scale can be changed by altering playback speed, data can be analyzed in several different ways, and by recording two or more tracks on the tape, coincidence experiments can be performed.

Although this method appears simple at first sight, it is by no means easy to get accurate, consistent results because of distortion introduced in recording and playback. If a number of identical pulses are recorded on the tape, it is found on playback that there is a spread in the pulse heights. With great care this can be reduced to ~1.5% (14). This spreading is a direct consequence of the analog nature of the recording process and is caused by small changes in tape quality, tape speed and tape-to-magnetic-head contact pressure. Resolution is also very sensitive to the amount of high-frequency bias used on the recording head (13, 15); each reel of tape must be run through several times to find the bias that gives the best resolution.

In an attempt to overcome changes in playback speed affecting pulse amplitude, Burgwald and his colleagues use a magnetic-modulator playback head (9, 16). Since the output of such a head is proportional to flux in the tape rather than rate of change of flux as with a conventional head, the output should be less dependent on speed fluctuations. Various head configurations were tried, but so far the resolution is no better than that from a conventional velocity-sensitive playback head.

Automatic Gain Compensation

Baumgardner has used a specially designed deck to reduce speed fluctuations and proposes to record a constant amplitude clock track along with the data. This track would be monitored on playback and used to adjust the gain of the amplifier for the data track. Such a procedure would tend to eliminate any fairly slow changes in tape quality, head contact pressure or tape speed.

The final limitation with analog recording is in the nature of the reel of magnetic tape. Since the manufacturers usually specify that gain fluctuations will be less than ½ db (6%) a reel, results as good as 1%–2% can be obtained only by careful selection of reels. Any substantial improvement awaits the development of better methods of tape manufacture to give greater uniformity.

For some experiments the accuracy obtained with analog recording is sufficient. For example, Rae and Firk (17) have investigated gamma-ray spectra following neutron capture with the equipment of Cavanagh and Boyce (13). Two tracks were recorded on ¼-in. tape. One contained the pulse heights of the gamma-rays, the other a pulse whose size defined the energy of the neutron causing the interaction. Recording tape speed was 0.8-in./sec; playback was at 15-in./sec. The users were able to repeat a previous experiment with greater statistical accuracy and resolution and derive the spin of the 34-ev neutron resonance in Hg^{200} from the shape of the gamma-ray spectrum.

printed-circuit computer logic elements. Since the memory is capable of storing 1,023 different words, for a complete analysis a tape must be replayed 32 times. But with tape speed 10–100 times that of recording, analysis takes only 0.3–3 times as much time as did the original experimental run. Since the memory can accept data from only 10 of the 15 tracks that lead into the memory, the other tracks are preset with switches before each run. Thus a word is read into the memory only if the five preset bits are the same as those on the corresponding five tracks on the tape. Otherwise the word is ignored. Each time a word occurs on the tape that can be accepted by the memory, the content of that particular address in the memory is increased by one. After the tape has been run through, the memory indicates the number of times that each of 1,023 words occurs; that is, the distribution of experimental data. Data from the memory is finally punched out onto paper tape in octal notation.

New model. With the experience gained from the use of the first analyzer, a second one has been built by E.M.I. with certain modifications to improve flexibility. The memory can also store only 1,023 different words, but its capacity per word has been increased from 1,000 counts to 65,500 counts. A patch panel has been incorporated so that any 10 of the 15 tracks can be selected for storage in the memory. A cathode-ray-tube memory-content display has been provided. The punch-out is now on cards in octal form and provision has been made for the connection of a pen recorder so that data can be plotted directly in analog form. The tape transport has been changed to one that runs at 120 in./sec and is bidirectional so that analysis can procede without rewinding of the tape between passes.

Multidimensional Analysis

Of the 16 tracks that can be recorded on the tape, one is a clock track that records a pulse every time a word is written. The other 15 can be split up in several ways. It is possible to perform several experiments in rapid sequence and record all the data on the same tape by using one or more tracks for coding. Suppose that you want to alternate counting and background runs with a pulse-height analysis

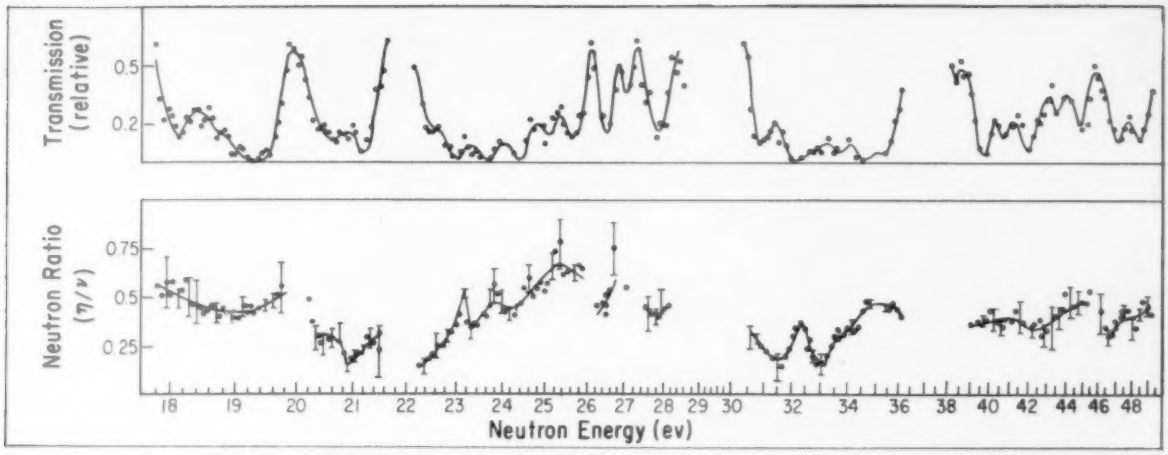


FIG. 6. ETA OVER NU AND NEUTRON TRANSMISSION for U^{235} as measured with 4,095 time-of-flight channels (6). Liquid scintillators detect fissions. Pulse-shape discrimination (7, 8) counts neutrons and rejects gamma photons

setup. You need only record a "1" in one track when the background is being run and a "0" in the same track for the sample count. The analyzer automatically sorts the two out and adds together the relevant groups of data. Coincidence information or other data of this type can be recorded just as easily with the analyzer collecting the data together.

One can split up the 15 bits available into two smaller words, each of which can be used to convey information. For example, one can have eight bits to record a neutron energy in 256 channels, and the other seven bits for 128 channels of gamma-ray energy. Since all 15 bits are recorded at the same time, both sub-words must come from the same physical event. When the analyzer has scanned the tape for all the 32,000 different words that are possible, a true three-dimensional picture can be built up; in this example dimensions are gamma-ray energy, neutron energy and total number of counts (see box, Fig. A). Figure B in the box comes from a similar experiment in which two pulse heights were recorded.

In many experiments it is of enormous advantage to build up three-dimensional graphs at one time. This is especially easy to do with a digital tape-recording system, and the method produces comprehensive results since there are so many channels available. The limitation of the relatively long dead time is not too serious since this type of experiment generally has small counting rates. If a three-dimensional analysis is attemped in the conventional way by repeating a two-dimensional analysis many times with different settings of the third variable each time, the experimental time required becomes prohibitive.

Time-of-Flight Analysis

Brooks and Rae have used our recording system to measure η/ν_{avg} for U^{235} as a function of neutron energy (6) (η is the number of fission neutrons emitted per neutron absorbed; ν_{avg} is the average number of prompt neutrons emitted per fission). In such analysis the tape recorder was used to record 4,095 channels of time-of-flight information with a channel width of ¼ μsec. The experimental arrangement of the recorder is shown in Fig. 4 (left).

The fission detector consisted of four liquid scintillation counters used with pulse-shape discrimination (7, 8) to count neutron interactions and reject gamma-ray pulses. Incident neutron energy was defined by neutron time of flight. The tape was analyzed in four passes through the analyzer. Figure 6 is typical of the results obtained.

Computer Analysis

With large digital computers that have magnetic-tape input one could analyze directly with the computer. Since these machines are capable of storing 36-bit words or longer ones, all the analysis could be done at one pass of the input tape. The output would be on magnetic tape for off-line printing. Since the magnetic-tape analyzer is by far the most expensive part of the tape system, a lot of time could be purchased on a large digital computer for the cost of a special magnetic tape analyzer. This approach appears to be the most promising for small physics laboratories for which the expense of a special tape analyzer can not be justified.

* * *

While this report was being written, J. R. Waters was a member of the Linear Accelerator Project of Rensselaer Polytechnic Institute, Troy, N. Y., and he would like to thank the personnel of that project for their encouragement and assistance. The Linear Accelerator Project operates under a contract from the U. S. AEC.

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Parent Activity from Daughter Growth

By YIZHAK MARCUS, *Israel Atomic Energy Commission Lab., Rehovoth, Israel*

MEASURING ACTIVITY and time of separation of a radionuclide with a long half-life is difficult; to do it accurately often takes many years of experimental observations. When a short-half-life daughter is available, however, we can measure the growth of the daughter nuclide and then use a curve-fitting method to determine the two unknowns.

In this method we plot the measured activity of the radioactive daughter as a function of time on one graph. These points are then compared with a calculated curve until the best possible fit is found (Fig. 1). The location of the new origin on the experimental curve determines both equilibrium activity and time of separation.

This curve-fitting method has two main advantages over other ways of finding equilibrium activity. First, it yields a more accurate value of the daughter equilibrium activity A_∞ from data extending over little more than one half-life of the daughter product. Second, it determines three parameters simultaneously (*1*). The third parameter is an approximate value for the half-life of the growing daughter, which one can find from a family of curves like that in Fig. 2, plotted with half-life as a parameter. The curve on which the experimental points fit best yields the half-life.

Theory. Since decay of a long-life parent is negligible, the daughter activity $A(t)$ at time t after separation is

$$A(t) = A_\infty(1 - e^{-0.693t/T_{1/2}}) \quad (1)$$

A_∞ is the activity of the sample at secular equilibrium and $T_{1/2}$ is the half-life of the daughter. Dividing by A_∞ and taking the logarithm one gets

$$\log \frac{A(t)}{A_\infty} = \log A(t) - \log A_\infty$$
$$= \log (1 - e^{-0.693t/T_{1/2}}) \quad (2)$$

From this equation one can see that on a graph of log A as a function of time a change in the constant A_∞ will only shift the axes vertically; similarly a change in the time scale from an arbitrary zero to a zero at the time of separation shifts the axes horizontally.

Curve-fitting method. We now apply the curve-fitting method to find equilibrium activity A_∞ and time of separation from data extending over little more than one half-life of the daughter. To do this, first measure the activity of the daughter $A(t')$ at time t' past some arbitrary zero. Then let the difference between the unknown time t measured from the moment of separation and the known time t' be t_0; thus $t_0 = t - t'$.

The problem is now reduced to finding A_∞ and t_0 by curve fitting. Draw the curve defined by Eq. 2 for log $[A(t')/A_\infty]$ on one graph. Then using the same scale, plot log $A(t')$ as a function of t' on a separate piece of transparent graph paper. Superimpose the two sheets and find the position where the experimental points best fit the calculated curve. Then when the origin on the calculated curve is transferred to the experimental curve, equilibrium activity appears on the vertical axis and time of separation on the horizontal axis.

Example. Apply this method to the growth of the upper state of Bi^{210} (5-day half-life) in a sample of initially pure parent Pb^{210} (19.4 year half-life) (*2*). First use Eq. 2 to plot a calculated curve. (The equation applies only if soft betas from Pb^{210} are properly masked off and only hard betas from the growing Bi^{210} are counted.) Then plot against time on a separate piece of graph paper the logarithms of the following counting-rates (cpm) recorded at 8:30 a.m. on each day from January 17th to January 25th: 105 ± 5, 153 ± 5, 200 ± 5, 240 ± 6, 302 ± 7, 367 ± 4. Match these experimental points with the calculated curve and transfer the origin coordinates from the calculated curve to the axis of the experimental curve (Fig. 2). t_0 is then given by the point where the zero from the calculated curve intersects the t' axis; A_∞ is given by the antilogarithm of the point where the zero intersects the log $A(t')$ axis. In this manner, one finds that $t_0 = -1.7$ days, log $A_\infty = 2.70 \pm 0.01$, $A_\infty = 500 \pm 10$ cpm. Since t' is measured from the 17th at 8:30 a.m., the moment of separation was ~3:45 p.m. on the 15th.

* * *

Thanks are due to Mrs. Abrahamer for the counting data.

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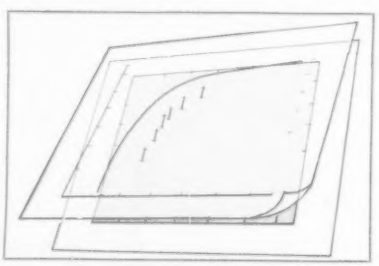


FIG. 1. CURVE FITTING gives activity and time of separation of parent with long half-life from measured growth of daughter

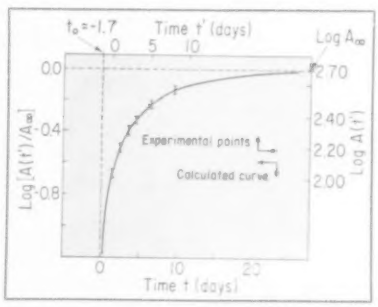


FIG. 2. PLOT OF Bi^{210} growing into Pb^{210} gives A_∞ of 500 ± 10 cpm and t_0 of -1.7 days when fitted to calculated curve

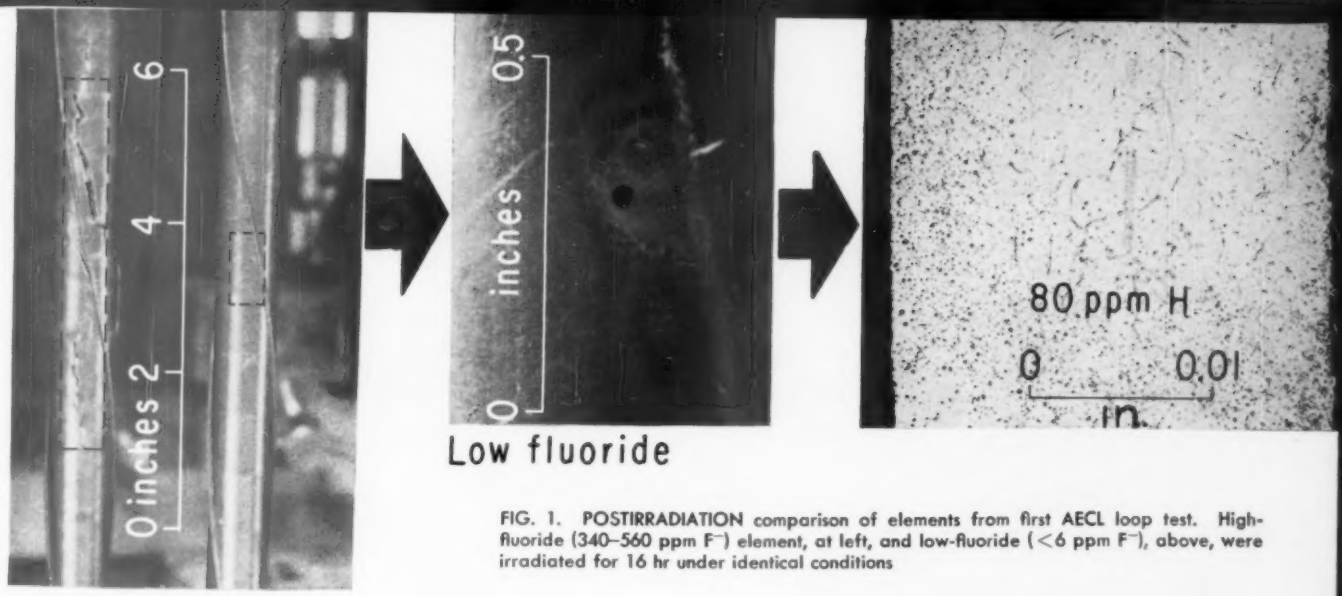
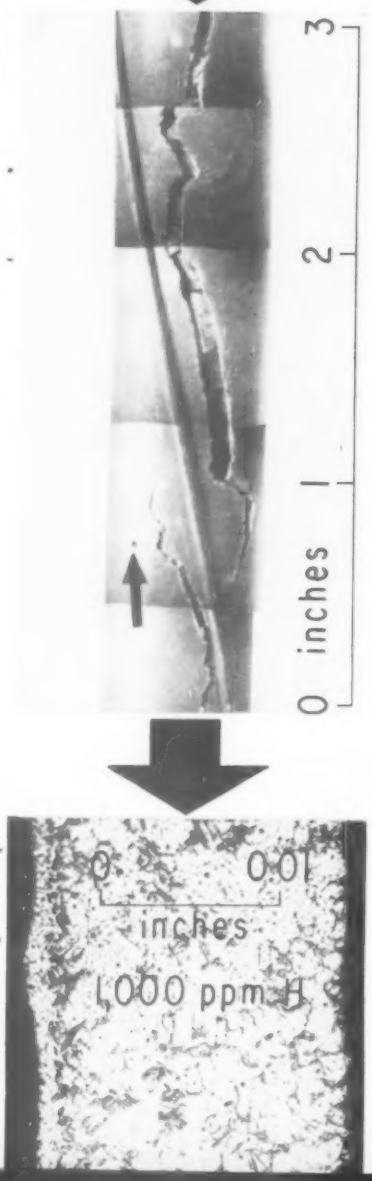


FIG. 1. POSTIRRADIATION comparison of elements from first AECL loop test. High-fluoride (340–560 ppm F^-) element, at left, and low-fluoride (<6 ppm F^-), above, were irradiated for 16 hr under identical conditions



Zircaloy-UO_2 Failures Tied to Fluorides

In-pile tests of Zircaloy-clad UO_2 indicate that high fluoride content caused Dresden prototype fuel to fail in VBWR. Thus, AECL confidence is unshaken

By M. J. F. NOTLEY and J. A. L. ROBERTSON
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IN 1959, DEFECTED ZIRCALOY-SHEATHED UO_2 fuel elements failed with extensive cracking after very short irradiations in the GE Vallecitos Boiling Water Reactor (*1*, *2*). On the other hand, this fuel type has performed well in the Shippingport reactor (*3*), and extensive tests by AECL and the Bettis laboratory of Westinghouse have established the satisfactory behavior of their present fuel-element designs. In spite of the good results obtained by AECL and Bettis, misinterpretation of the VBWR failures has obscured the status of Zircaloy sheathing. Now, irradiation tests just completed at AECL show that the failures can be attributed to an accidental high fluoride content in the UO_2 used in the Vallecitos elements.

Zircaloy Experience

All laboratories have agreed on the excellent performance of nondefected Zircaloy-sheathed elements. But to test performance even more rigorously, elements are frequently purposely defected. (A defected element has a hole through the sheath which gives the coolant access to the fuel.) Even when defected elements are irradiated (*3*, *4*), the hydriding rate of Zircaloy during corrosion is within acceptable limits. One defected specimen showed no visible change after a 300-day irradiation, and none exhibited severe damage such as sheath cracking. The worst failure was an enlargement of the defect from 0.005 in. to ~¼-in. diameter after a 3½-day irradiation at the high surface heat flux of 500,000 Btu/ft²/hr; i.e., where the temperature of the sheath inner surface was as high as 375° C.

In contrast, the failures observed by the General Electric group at Vallecitos (*1*, *2*) occurred after irradiations as short as 36 hr at comparatively low

surface heat fluxes. The failures were much more severe than those seen elsewhere. Extensive hydriding of the Zircaloy sheaths was associated with multiple longitudinal cracking over half the elements' 27-in. length, with individual cracks up to 4 in. long.

Because of the unique behavior of these elements, it was suspected that they were not representative, and that failure could be attributed to some extraneous property of this particular batch. Several possible explanations were examined by the General Electric Atomic Power Equipment Dept. groups at San Jose, Calif. (henceforth called GE) and by AECL groups at Chalk River: differences in fuel diameter, surface heat flux, fuel/sheath clearances and coolant conditions were all considered but thought to be unimportant. In their most recent report of the failures, however, Naymark et al. of GE (*2*) mention that these specimens contained UO_2 with a high fluoride content. Subsequent information from GE, San Jose, revealed that samples of sintered UO_2 from the batch used in their failed specimens contained 800 ppm fluoride and >1,000 ppm calcium introduced accidentally as CaF_2 in the UO_2 fabrication (*5*). In view of the markedly deleterious effect that very small amounts of fluoride have on the aqueous corrosion of Zircaloy (e.g., the rapid corrosion of pickled Zircaloy that has been inadequately rinsed), this appeared to us to be the most probable cause of the failures.

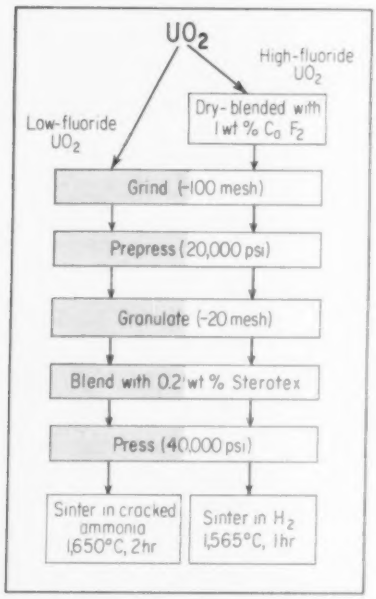

FIG. 2. UO_2 PELLET fabrication flowsheet. At left are conventional fabrication steps; at right are modifications necessary to incorporate fluorine in fuel

TABLE 1—Elements and Irradiation

Dimensions	
UO_2 diameter (in.)	
1st test:	0.744
2nd test:	0.740
Fuel/sheath diametral clearance (in.)	
1st test:	0.004
2nd test:	0.008
Fuel length (in.):	12
Sheath thickness (in.):	0.025
UO_2	
Density (gm/cm³):	10.45 ± .05
Enrichment (wt % U^{235} in total U):	1.9
Stoichiometry	
High fluoride:	$UO_{2.010\pm0.005}$
Low fluoride:	$UO_{2.008\pm0.005}$
Heat ratings (estimated)	
Heat output per unit length (w/cm):	600
$\int kd\theta$ (w/cm):	45
Surface heat flux (sheath/coolant)	
(w/cm):	99
(10^3 Btu/ft²/hr):	310
Sheath inner-surface (°C):	320
Coolant (water)	
Temperature (°C):	250
Pressure (psi):	1,400
*p*H (maintained by LiOH resin):	9.5–10.5
Oxygen content (ppm):	<0.1

Chalk River Irradiations

To test this hypothesis, pairs of defected specimens were irradiated at Chalk River in a pressurized-water loop. The elements in each pair were identical except that the UO_2 in one contained 340–560 ppm by weight of fluorine introduced as CaF_2, that in the other containing <6 ppm. The specimens with the high fluoride content failed rapidly with extensive sheath cracking (Fig. 1), duplicating GE experience, whereas the low-fluoride ones were virtually unchanged, duplicating Bettis and AECL experienced. Thus the GE results are attributed to impurities in their UO_2.

Experimental details. Table 1 shows the specimen dimensions and irradiation data. A flowsheet (Fig. 2) gives details on the fabrication of the UO_2 pellets. Except for the impurities in the UO_2 (Table 2), the pairs of specimens were identical.

The specimens were irradiated in adjacent positions in a pressurized water (X-2) loop of NRX, on either side of the center line of the neutron flux. In each test, the high-fluoride element was uppermost (i.e., downstream) so that the low-fluoride element would not be grossly contaminated. The histories of the two loop tests are shown in Fig. 3, where the activity release into the loop and the reactor power level are plotted.

The greatest experimental difficulty in this test was to establish methods for incorporating such large amounts of fluoride in the UO_2. Additions of fluoride, either by adding HF (up to 50,000 ppm F) or dissolved UO_2F_2 (up to 140,000 ppm F) to uranyl nitrate solutions, or by dry-blending UF_4 (up to 25,000 ppm F) with ceramic-grade UO_2, resulted in dense sintered pellets containing much less than 60 ppm F in all cases (*6*). The decontamination factor on sintering (1 hr at 1,650° C) varied between 2×10^3 for UF_4 additions and 25 for UO_2 prepared from uranyl nitrate containing UO_2F_2. Only by adding CaF_2 and modifying the sintering cycle slightly (see Fig. 2) was it possible to incorporate sufficient fluoride in the sintered pellets.

Test results. Failures similar to those reported by GE (see illustrations in ref. *2*) occurred very rapidly.

The first test was discontinued 22 hr after the first reactor startup because all the instruments measuring activity in the loop had gone off-scale, even at steady power. Examination showed that the sheath of the high-fluoride element had suffered severe damage, having many large longitudinal cracks (Fig. 1), whereas the low-fluoride specimen was unchanged in appearance and dimensions. The metallographic section and chemical analyses (Fig. 1)

TABLE 2—UO_2 Analysis (ppm, wt)

	High fluoride	*Low fluoride*
Ca	3,750	3
F	340–560	6
Al	25	
Cr	25	
Cu	13	1.5
Fe	230	2
Mn	5	
Ni	20	
Si	2	
Sn		1
Sr	3	

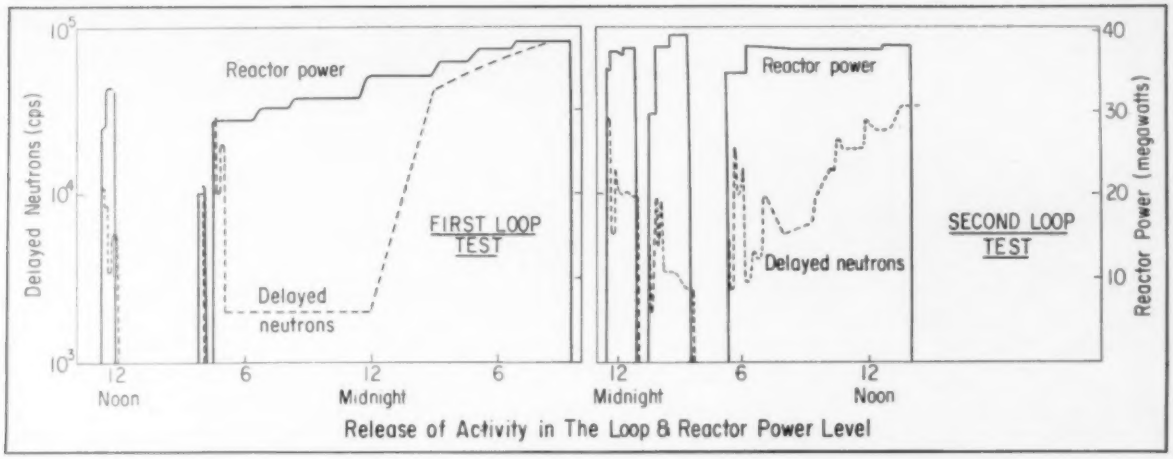

FIG. 3. ACTIVITY RELEASE in loop and NRX power level during irradiation of two fuel-element pairs

demonstrate a degree of hydriding not hitherto observed in Zircaloy sheaths tested at Chalk River.

The second test was a repeat of the first, except that the fuel/sheath diametral clearance was higher (0.008 in. compared with 0.004 in.). These specimens were removed after 15 hr to avoid excessive loop contamination, the activity in the loop having started to rise significantly after 10 hr (Fig. 3). The failed element appeared very similar to the previous one, though cracking was not as pronounced.

Conclusion

These tests show conclusively that impurities in the UO_2 can cause catastrophic failure of the Zircaloy sheaths of defected elements. Although the rigorous deduction is that either the calcium or the fluoride have this effect, it is probable that the latter is more important. Since the failed specimens were similar to GE's elements with respect to fluoride content and exactly reproduced the nature of the damage, we attribute the VBWR failures to the use of impure materials.

The difficulties experienced in incorporating the fluoride make it well-nigh impossible that this error could be repeated accidentally in fuel production. The possibility of similar failures to those at VBWR can therefore be eliminated. With a clearer understanding of the VBWR failures, the many fuel elements that have operated satisfactorily can now be judged on their own merits.

The authors appreciate the assistance of the following: W. T. Bourns for preparation of the UO_2 powders, G. H. Chalder and E. Barnes for sintering trials and manufacture of the pellets, E. Mizzan and M. B. Watson for element assembly, J. Christie and Reactor Loops Branch under the direction of R. F. S. Robertson for conducting the irradiation, G. M. Allison for monitoring the loop, R. D. MacDonald for postirradiation examination of the elements, and R. W. Ashley and G. Parry for sheath analysis and examination.

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At NUCLEONICS' Invitation—Comments by S. Naymark, GE-APED, San Jose

In early 1959, intentionally ruptured prototype fuel elements were placed in the VBWR as part of an experimental program to study (a) the effect of a fuel rupture on the reactor system, (b) the conditions which might lead to rapid propagation of the failure, and (c) leak-detection systems. A preliminary internal report was reported early in 1960 which indicated that high fluoride content might have been one of the contributing factors to propagating failures.

Subsequent analysis of the early experimental elements which developed extensive clad failures showed that they contained UO_2 powder with an original fluoride content of 200–1,000 ppm. As a result, a specific test program was begun to determine the effect of fluoride on Zircaloy cladding. Later, discussions were held with the Chalk River experimenters who were acquainted with our test program as we were with theirs.

Every effort is being made by GE and others to determine whether fluoride was the primary or one of the contributory reasons for cladding-failure propagation. The Chalk River experiments, although conducted for short periods of time (15 and 22 hr), form a valuable part of this analysis. Further tests (now underway at GE-APED), for a much longer irradiation time than reported by AECL, are necessary to determine the effect of operating time on Zircaloy-clad fuel with up to 15 ppm fluoride.

The early experimental VBWR fuel elements, although similar to the Dresden fuel in diameter and geometry, did not feature the same degree of material and fabrication quality. In addition, the UO_2 powder in the Dresden pellets contained only 15–75 ppm fluoride, well below the 200-ppm specification. The manufacturing problem experienced with the first Dresden elements—small cracks in the Zircaloy cladding in 3% of the fuel rods [NU, January, 1960, p. 18]—was unrelated to the VBWR hydriding failures and was resolved through improved fabrication and inspection procedures, before initial criticality in October, 1959.

It is important to recognize that many factors enter into the choice of fuel cladding for a particular reactor. As an example, data from Shippingport and others indicated increased severity of Zircaloy hydriding in defects at higher heat fluxes. Other factors considered are the clad effects on fuel economics, clad reliability throughout fuel life and clad operating temperatures. Based on the results of our continuing development programs, we will select the most reliable and economic material for the conditions of temperature and heat flux to which it will be subjected.

2 Articles on EBWR

1 Radiation Levels in EBWR

By VINCENT C. HALL, Jr. and ROBERT H. LEYSE, *Argonne National Laboratory, Lemont, Illinois*

ONLY MINOR CONTAMINATION of primary-system components external to the reactor vessel has resulted from 4 years (8,850 Mwd) of operation of EBWR, the direct-cycle, natural-circulation Experimental Boiling Water Reactor (*1–3*). This contamination does not significantly interfere with maintenance operations. The only serious problem associated with contamination from long-lived radionuclides has been caused by a concentration of corrosion products at the bottom of the reactor vessel. A radioactive scale deposited on the fuel elements may be a source of difficulty in the long run.

Short-Lived Activity

Short-lived radionuclides determine accessibility of plant equipment during operation. Nitrogen-16, with a 7.4-sec half-life, accounts for >90% of the activity measured during operation; fortunately only 0.1% of the N^{16} formed enters the steam to be carried out of the reactor vessel, and 99.9% remains in the reactor water (see article on opposite page).

During reactor operation, activity levels at the surface of the major pieces of equipment are monitored. Typical activities, attributed primarily to N^{16}, at various reactor power levels are given in Table 1.

Long-Lived Activity

After the reactor is shut down, accessibility to plant equipment is determined by longer-lived radionuclides that result from neutron activation of corrosion products. The radionuclide content of reactor water varies with reactor conditions, but a typical radiochemical analysis shows Na^{24}, Mn^{56}, Co^{58} and Co^{60} (see Table 2). These arise from the neutron activation of Al^{27}, Fe^{56}, Ni^{58} and Co^{59} in corrosion products.

The major portion of the aluminum corrosion product comes from the dummy assemblies used to fill out the grid plate surrounding the active core region. Most of the nickel comes from the nickel-nickel-phosphide plating in the main steam lines, turbine diaphragms and turbine-exhaust casing. The iron, of course, is from corrosion of the steel of the reactor vessel and primary-system piping.

A fraction of the radioactive nuclides in the reactor water will carry over with the steam to the turbine and condenser in a direct-cycle system. In a series of tests on EBWR using Na^{24} tracer, 0.02% of the Na^{24} activity in the reactor water entered the steam and was carried to the external system. There are no data for Co^{58}, but it should behave like Na^{24}.

Cobalt-58 is the major source of activity encountered during the maintenance of plant equipment after reactor shutdown. The other nuclides, Na^{24} and Mn^{56}, decay to negligible values during the period required to reduce the temperature of the reactor system so that maintenance operations can proceed. Typical surface activities are given in Table 3.

The activities indicated in Table 3 were measured after the reactor plant had operated for about 1 yr. During the succeeding 18 months of operation activity measurements at 3-month intervals have shown no appreciable changes from the values given.

Fuel-Surface Deposits

The corrosion products, which are

(*Continued on page 82*)

TABLE 1—Radiation Levels (Primarily N^{16})*

	Radiation level (mr/hr)			
	Reactor power [Mw(th)]			
Location	*10*	*20*	*40*	*61.7*
Air ejector after cooler	90	400	4,000	7,000
Condenser hot well	10	40	240	580
Steam drier	80	150	600	720
Turbine-exhaust casing	2	4	14	20
Feed-water filters	8	10	50	100
Plant air exhaust	6	12	40	120

* Measurements made 2 in. from surfaces during operation at power shown.

TABLE 2—Activities in EBWR Water*

Nuclide	*Formation*	*Half-life*	*Specific activity (10^4 dpm/ml)*
Na^{24}	$Al^{27}(n,\alpha)Na^{24}$	15 h	20
Mn^{56}	$Fe^{56}(n,p)Mn^{56}$	2.6 h	6
Co^{58}	$Ni^{58}(n,p)Co^{58}$	71 d	0.4
Co^{60}	$Co^{59}(n,\gamma)Co^{60}$	5.2 y	0.04
Other			<0.02 each

* Reactor power: 20 Mw(th); ion exchange flow: 10 gpm.

Radioactivity Buildup

2 N^{16} Concentration in EBWR

By ROBERT L. MITTL* and MICHEL H. THEYS,† *Argonne National Laboratory, Argonne, Illinois*

EXPERIENCE with EBWR has shown that during the operation of a boiling-water reactor, 7.4-sec N^{16} is by far the major source of radioactivity in the steam circuit (see Table 1, p. 80). Therefore, we have studied the mechanisms of N^{16} production in the water and transfer to the steam.

The N^{16} originates from the fast-neutron (9–18 Mev) reaction, $O^{16}(n, p)N^{16}$, with the oxygen of the coolant water (*1*). Most of the decay occurs during one cycle in the steam and condensate system; 78% of the decays are accompanied by gamma rays, 73% of energy 6.13 Mev and 5% 7.12 Mev (*2*).

Two questions immediately occur: Will the N^{16} level limit accessibility to components and piping that contain steam? What are the potential hazards of a system that would release steam to the containment vessel?

In answer to the first question, we have found that in the EBWR less than 1.0% escapes into the steam. This produces an equilibrium concentration of about 10^6 atoms/gm of steam, which has proved too small to interfere seriously with accessibility to areas within the containment vessel during operation of EBWR up 40 Mw(th). The short half-life of N^{16} (7.4 sec) also prevents the activity carried by the steam from concentrating in the condensate and feedwater systems. Although the radiation level from N^{16} near the steam dryer and air ejectors is high enough to limit the stay of personnel in these areas, it has always been possible to accomplish the maintenance work, experiments and tests within the prescribed exposure limits. There has been no need to operate components remotely.

The origin and half-life of N^{16} bear on the second question concerning hazards potential. With shutdown of the reactor upon a steam-system rupture, N^{16} production would immediately cease and, because of the short half-life, the N^{16} would decay away rapidly.

Experiments in EBWR indicate that the fraction of N^{16} that enters the steam depends on the proportion of volatile N^{16} radicals formed relative to nonvolatile radicals. The addition of excess hydrogen to the coolant system apparently increases formation of volatile radicals and hence the N^{16} concentration in the steam. There appears to be no convenient way to bring about the reverse—decrease the N^{16} in steam below normal levels.

These experiments provide important information for predicting N^{16} radiation levels and the shielding needed for higher-power operation of EBWR and other boiling reactors.

Experimental Method

The N^{16} concentration at different locations in the reactor vessel was obtained by continuously sampling the water and steam and measuring the γ-ray activities.

A scintillation counter detected the high-energy γ-rays, and a discriminator identified the N^{16} activity by counting only pulses corresponding to energies >4.5 Mev. Both decay curve and spectrum of the radiation identified the activity as N^{16}.

To determine the concentration of N^{16} per gram of coolant for a given point in the reactor vessel, the counter was calibrated with a standard cobalt-60 solution (with adjustment for γ-ray energies). Counting-rate corrections were made for N^{16} decay and for the noncondensable gas in the sample.

Usual methods of chemical analysis cannot be used with N^{16} because of the short half-life. Information about the proportions of anion, cation and neutral N^{16} species was obtained by passing samples through ion-exchange beds and then counting their activities.

To determine relative amounts of anion and cation species of N^{16}, three beds (anion, cation and inactive) were employed. The inactive bed removed no N^{16} and thus indicated the activity decrease by decay. Comparison of this count with the anion-bed and cation-bed counts then determined the fraction of anion or cation species originally present.

Experimental Results

A series of experiments to determine N^{16} concentration and chemical form in steam and water were performed at EBWR while operating over a range of pressures and power levels and with known chemical additives.

Chemical form of N^{16}. Since N^{16} appears as a recoil atom with varying degrees of ionization and since the reactor coolant water is of high purity (conductivity of 2 μmhos), most of the N^{16} can be expected to combine with oxygen and hydrogen atoms. Possible

(*Continued on page 83*)

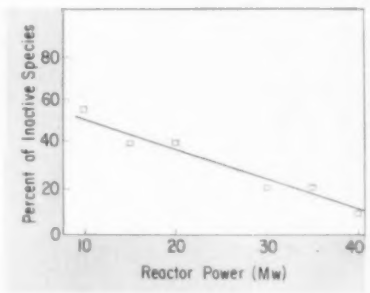
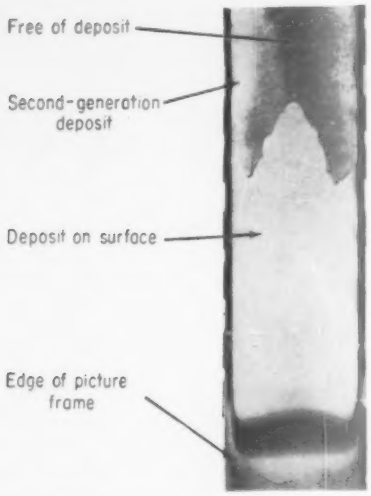


FIG. 1. NEUTRAL-CATION distribution of N^{16} in reactor steam 92 in. above fuel under normal operation

*On loan from Public Service Electric and Gas Co. PRESENT ADDRESS: General Atomic, Div. of General Dynamics Corp., San Diego, Calif.

† PRESENT ADDRESS: 30 Chaussée de Machelen, Melsbroeck, Belgium.



CORROSION-PRODUCT deposits on lower half of EBWR fuel plate after 2½ yr in reactor. White area in lower part of photograph is deposit scale; scale flaked off darker area. Dark area shows evidence of second-generation deposit. Outline of cladding frame is evident

the source of the long-lived radionuclides, have created another more serious problem.

As the corrosion products pass up through the reactor core they are deposited on the surfaces of the fuel plates (see the photograph); the deposition is roughly proportional to the reactor flux. The deposit continues to accumulate until finally it tends to flake off the fuel surfaces. The flaking off is thought to result either from a differential expansion between the scale and the fuel surface or from a fuel-plate temperature increase with increasing scale thickness sufficient to cause a chemical transformation of the scale.

The thickness of scale samples obtained from the fuel surfaces as well as from the bottom of the reactor vessel has varied from 0.003 to 0.007 in. However, any one sample has been of uniform thickness. Composition of the scale is shown in Table 4.

It is assumed that scaling impairs the heat-transfer characteristics of the fuel plate, and as a result the surface temperature of the fuel plate has undoubtedly increased. However, a metallurgical examination of fuel after 0.37 at% burnup has not revealed deterioration of the fuel plates.

It is not known what the long-range effect of the corrosion-product deposition will be on the performance of the fuel assemblies. Eliminating the sources of the corrosion products that make up the scale deposit would certainly be a step in the right direction. The aluminum from the dummy assemblies and the nickel from the nickel-nickel-phosphide plating in the steam system constitute 93% of the observed deposit. Thus, if these materials had not been present, the scale would have a thickness of only 0.0003 in., or a factor of 10 less than what is presently observed.

When the scale flakes off the fuel plates, it settles into the stagnant areas at the bottom of the reactor vessel. In EBWR, these stagnant areas are the control-rod-drive thimbles, which protrude below the shielding into the subreactor room.

During the first year of operation, the background activity in the subreactor room was ~10 mr/hr. As a result of the settling of the activated corrosion products, this activity has increased to 100 mr/hr. The activity at the surface of the thimbles, which require occasional maintenance, has been as high as 90 r/hr.

As a result of this increase in activity in the subreactor room, the EBWR control-rod drives have been redesigned. The original design did not have provision for flushing these stagnant areas; the new design provides blowdown with high velocity past all surfaces so as to flush corrosion products out of the system.

TABLE 3—Activities after Reactor Shutdown*

Location	*Activity (mr/hr)*
Steam drier	20
Steam turbine	
Steam chest	5.0
Blades	0.2
Condenser	
Top of tube bank	0.2
Hot well	2.0

* Reactor had operated 1 yr. Measurements made 2 in. from internal surfaces.

TABLE 4—Composition of Fuel-Plate Deposit

Oxide	*wt %*
$Al_2O_3 \cdot H_2O$ (Bohmite)	80.6
NiO	12.6
Fe_3O_4	5.1
SiO_2	1.6

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Vallecitos Experience Agrees

In line with the EBWR findings, General Electric's Vallecitos Laboratory also reports that the radioactivity deposited in their boiling-water-reactor water and steam systems has been lower than originally anticipated.

After 8,000 hr of operation, the turbine-surface contamination gave dose rates of 1–3 mr/hr at the surface. Although the reactor operated for extended periods with defected fuel in the core, activated corrosion products were the predominant radioisotopes in the surface deposits, both in the turbine and in the water and steam systems.

At the present time, after two years of reactor operation, over half of the surface radioactivity is attributed to Co^{60}, at times as short as 2 days after reactor shutdown. Other long-lived radioisotopes present were Zn^{65}, Co^{58}, Cr^{51} and Mn^{54}. Contamination levels in the steam piping were 0.1–0.01 of those in the water system and apparently increased with time at an unexpectedly slow rate.

(This information is based on a paper presented by D. W. Danielson, T. F. Evans and G. G. Gaul of Vallecitos Atomic Laboratory, General Electric Co., San Jose, Calif., at the American Nuclear Society meeting, Chicago, June, 1960.)

chemical forms include anions (NO_2^-, NO_3^-, . . .), cations (NH_4^+, . . .) and neutral species (NO, NO_2 . . .). The very low concentration of N^{16} makes it improbable that any ion contains more than one radioactive nuclide.

After its production, N^{16} combines mainly in an anion form which remains in the water. Within the experimental accuracy, only cation and neutral but no anion species were detected in the steam. In like manner, no neutral species could be detected in the water—this is because of the recirculation ratio of about 50 to 1 at 20 Mw(th) and the almost complete stripping of gaseous compounds.

Under normal operating conditions, the anion and cation species in the water are in the ratio of about 7 to 1. In the steam, the ratio of neutral (inactive) to cation species decreases with increasing reactor power (Fig. 1).

Effect of chemical additives. To gain an understanding of the separation mechanism of N^{16}, various additives were introduced into the reactor feedwater so as to disturb the relative amounts of anion and cation species.

Nitrogen, oxygen and argon gas had no apparent effect on the ion form of N^{16} and, hence, on steam activity. The addition of hydrogen gas (Fig. 2), hydrazine or ammonia decreased the anion-to-cation ratio in the water and hence increased the activity in the steam above the normal value. At 20 Mw(th), 600 psig and 489° F, the addition of 40 cm^3 of H_2 per liter of feedwater led to nearly equal proportions of anions and cations in water. At the same time, the steam and condensate-system monitors indicated an increase in radiation by a factor of four. No change was observed in the total water activity since the amount of N^{16} in the steam was still a small fraction of the total produced.

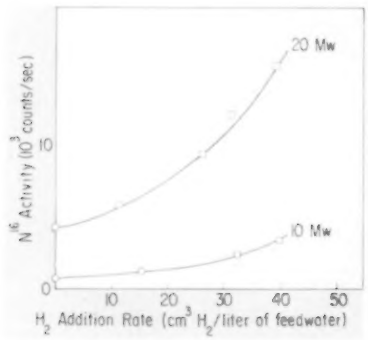

FIG. 2. HYDROGEN-ADDITION effect on N^{16} activity in steam 112 in. above fuel

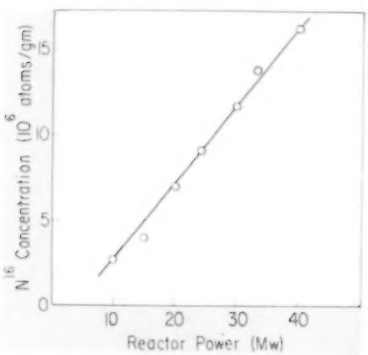

FIG. 3. REACTOR WATER concentration of N^{16} 52 in. above fuel

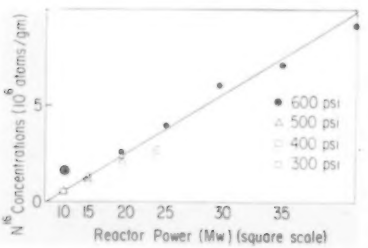

FIG. 4. OPERATING PRESSURE effect on N^{16} in steam 92 in. above fuel

Effect of power, pressure and water level. The N^{16} concentrations at points in the reactor water above the core and in the steam in the upper portion of the reactor vessel were measured as a function of reactor power. In the water, 52 in. above the fuel, the concentration was approximately proportional to reactor power (Fig. 3), while in the steam, 92 in. above the fuel, the concentration appeared proportional to the square of the power (Fig. 4).

The effect, if any, of reactor operating pressure on the water and steam concentrations of N^{16} and on the relative amounts of anion and cation species in the water was too small to be detected (Figs. 1 and 4). The steam activity external to the reactor vessel increased with decreasing pressure owing to increased steam velocities.

As the water level within the vessel was lowered, the amount of N^{16} at a given elevation in the reactor water increased and in the reactor steam decreased. These changes can be attributed to the variation of the steam and water velocities within the vessel and thus to the N^{16} decay.

Steam-water distribution. As indicated in the previous sections, the ratio (α) of N^{16} in steam to N^{16} in water increases with the addition of certain chemicals and reactor power. Work at BORAX-III established that decreasing the *p*H of the reactor water increased α (*3*).

These three conditions of reactor operation also cause an increase in the mass flow of hydrogen gas through the reactor water above the core. If it is assumed that the distribution of N^{16} between anion and cation species is a function of chemical equilibrium established in part by hydrogen-gas concentration, it is possible to account for part of the variation of α.

Part of the cation species are volatile, permitting their appearance in the vapor phase. Opposed to this, the anion species remain in the liquid phase. Thus, any disturbance that shifts the anion-cation equilibrium in water in the direction favoring cations will increase the N^{16} concentration in steam. If increased hydrogen gas increases the cations at the expense of anions, any condition of reactor operation that increases hydrogen concentration will increase α.

But this is not the only source of variations in α. An increase in reactor power is accompanied by an increased tendency for N^{16} cations to leave the liquid phase. The fraction, β, by which the N^{16} cation concentration in water decreases upon formation of steam varies with reactor power. We've shown that β is independent of the absolute concentration of cations; at 20 Mw(th), β remained unchanged during the addition of hydrogen gas, which increased the absolute concentration of the cation form. But β does appear to be power-dependent. We theorize that the amount of the cation form of N^{16} transported from the liquid to the vapor phase is related to the void fraction and the probability that a cation species in water will approach a water-steam interface.

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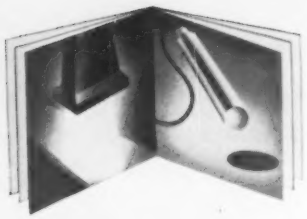
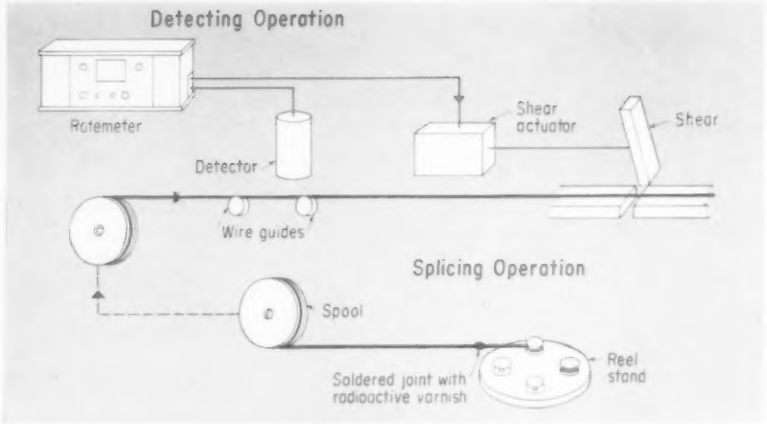


APPLIED RADIATION CASE HISTORY NO. 6



Radioactive Wire-Splice Tags

A drop of P^{32} varnish provides the signal for a shear that automatically removes splices from fast-running heating wire

By MICHAEL J. CLANCY, *Tracerlab, Waltham, Massachusetts*

A TINY POT of radioactive varnish and a scintillation detector are saving one manufacturer ~ $30,000 a year. His problem was to detect wire splices that were essential in a continuous wire-coating process before they were built into the product. After other methods had failed, we were able to develop a radiotracer system that more than meets the manufacturer's specification of not more than one false indication or missed splice in a day of operation.

What We Had To Do

In the operation with which we were concerned, plastic jacket is extruded onto heating wire at a rate of more than 30 miles/day. During each day 125 lengths of wire are spliced end to end so that the extrusion can be continuous. But splices must not end up in the product. They cause hot spots that burn out, and because they are less flexible than other wire, they break.

The manufacturer had previously tried and failed to detect the splices by their additional weight and increased stiffness. Finally he was forced to station a man at the extruder to mark the jacket as a splice entered—a method both expensive and unreliable.

Instrumentation

We settled on a system in which a drop of P^{32}-loaded varnish, applied by hand as a splice is made, triggers an automatic shear that removes the splice after extrusion of the jacket. Because of the jacket weight (260 mg/cm²) and the necessity of personnel remaining in the detection area we needed a beta emitter. Supply and disposal problems for the radiotracer suggest that a half-life longer than a week and shorter than a month would be convenient. P^{32} satisfies all of our requirements with 1.71-Mev betas and a 14.5-day half-life.

Under the present system the plant receives a shipment of P^{32} each Monday. The plant chemist mixes the tracer with varnish in such strength that one drop applied to a splice provides a label of the correct activity. The radioactive varnish is applied by hand with a small brush fitted with a shielding collar.

For a detector we use a 2-in. NaI(Tl) crystal feeding into a precision ratemeter, which, in turn, triggers the automatic shear. The ratemeter time constant has been set at 0.015 sec.

How Much Activity?

To determine how much activity we must put on each splice we made computations based on background counting rate, wire speed, detector viewing aperture and the manufacturer's requirement of not more than one miss per day. Since the wire moves at 340 ft/min, the 2-in. detector sees a splice for 0.0294 sec, and average background count during that interval is 0.148 count. Choosing as a criterion that random background should not exceed a random signal count more often than once in a million times, we find from the Poisson equation that we require five counts per splice. Thus we set our trigger counting rate at 10,000 cpm.

The further requirement that we miss no more than one splice in 125 means that the actual activity on a splice must be such that the count from a splice will be less than five only once in 125 splices. Statistics tell us that we need an average rate that will produce 12 counts per splice. Further adjustment for absorption, decay, geometry and variations in application lead us to 3×10^6 cpm, 1.5 μc per splice and a shipment of 1.4 mc of P^{32} once a week.

Present Operation

The system as it is now installed is totally adequate for reliable splice detection. On the average it gives nearly two days of operation without a miss or false signal. Economically it has been a boon. For a system cost of $3,300 and a P^{32} cost of $15 per week, it returns savings in material, rejects and labor estimated at $30,000 per year.

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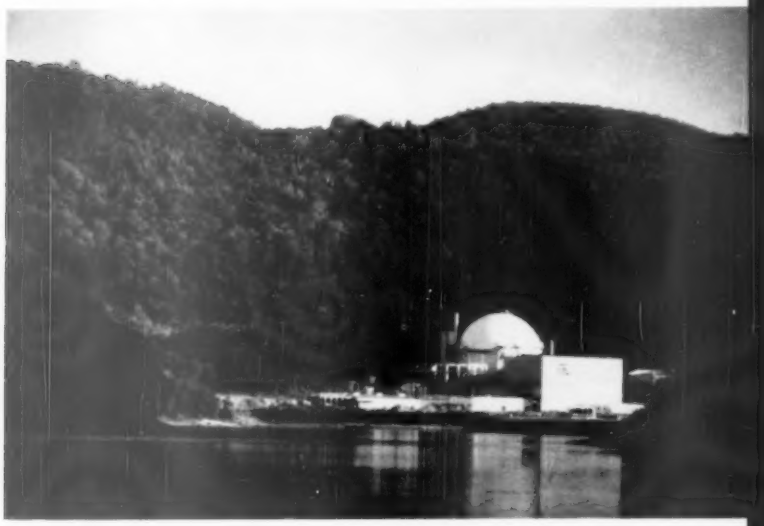
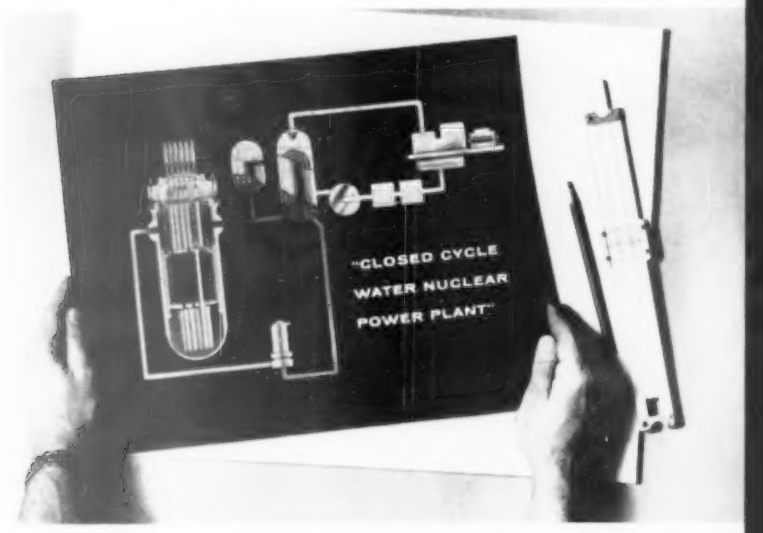


ON THE BOARDS

the new 375-Mwe atomic power plant is a giant step forward in the realm of controlled commercial nuclear power. Projects like this offer to professional personnel the opportunity to take part in the design and development of economic nuclear power plants. Career openings for qualified scientists exist in many areas. Some of these areas are listed in the next column.



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Currents from Gammas Make Detectors and Batteries

By BERNHARD GROSS and PRESTON VINCENT MURPHY, *Instituto Nacional de Tecnologia, Rio de Janeiro, Brazil*

Compton electrons scattered by a field of gamma photons can be collected to produce useful electric currents. When the source of gamma rays is an internal one, the system can be designed to make a new type of nuclear battery. When the gamma source is external to the system, the same type of device will serve as a dosimeter producing either a static charge proportional to dose or a current proportional to dose rate.

Gamma photons with energies between 0.3 and 3 Mev interact with small-atomic-number materials mainly by Compton scattering (*1*). Thus as the photons collide with atoms in their paths, the field generates a flux of Compton electrons that moves along with the gamma photons. When these electrons move between electrodes, they produce a current and the system then becomes a battery or a detector.

Unlike beta-ray direct-charging devices (*2*), a battery based on this principle is not limited by self-absorption in the source. Moreover it requires no vacuum and can supply essentially unlimited potentials. Unlike scintillation-photoconduction batteries (*3*), this kind has a single-step conversion of nuclear energy to electrical energy. The corresponding radiation detector has several advantages over conventional ionization chambers, principally a solid dielectric in place of a gas chamber and the absence of any requirement for a power source.

How It Works

Although both battery and detector convert gammas into current, the two devices actually operate in different directions. In our battery the source becomes positively charged when photons push Compton electrons to the edge of the insulator block (Fig. 1). In the radiation detector

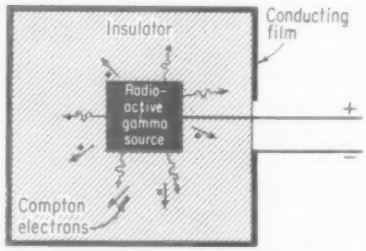

FIG. 1. GAMMA BATTERY. Compton electrons derived from gammas from source at center move mainly outward. Source then becomes positive and outer conducting film negative

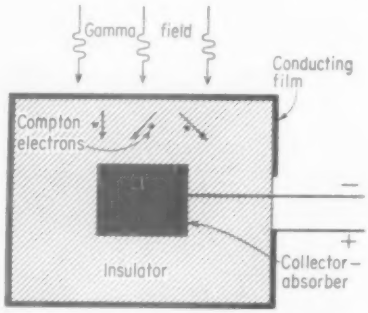

FIG. 2. GAMMA DETECTOR. Gammas enter insulating block; electrons from Compton interactions with atoms of insulator move to central metal absorber

the central area of the block becomes negative when the gammas and electrons enter it after traveling from the edge (Fig. 2). Thus, although gamma absorption in each case yields the current, the direction of movement of electrons and current is reversed in the battery and detector.

Battery operation. In making a battery we would enclose a gamma source in a metal disk imbedded in an insulating block coated with grounded conducting film. The metal source container is thick enough to achieve electron equilibrium. To eliminate boundary effects, we chose the atomic number of the container similar to that of the insulator. The gamma rays originally leave the source unaccompanied by electrons, but as they penetrate a few millimeters of a solid such as the isotope container, Compton electrons appear and their number grows to equilibrium with the photons. When gamma-electron equilibrium is reached, the electron flux remains proportional to the gamma flux and decreases as gammas are absorbed. As the photons and electrons move away from the source through the insulator, the source is left with a positive charge and becomes the positive electrode in the circuit. The grounded outer insulator surface becomes the negative electrode. For purposes of electrical analysis the fate of the electrons and photons that pass through the grounded outer surface of the battery is unimportant.

Electrons leave the source with varying energies; some are not energetic enough to penetrate the insulator. Since there is gamma-electron equilibrium, however, a new electron will be formed in the insulator for each one stopped. Consequently there is no buildup of negative space charge that could possibly reduce the Compton electron ranges; this is true at least for a relatively thin insulator in which one can neglect gamma-ray attenuation.

Each electron formed or stopped in the insulator will contribute d/D to the measured charge (d is the component of electron range in the dielectric normal to the electrode surfaces; D the distance between electrodes) (*4*). The measured electron current is then given by $I = nD(d/D)e$ or

$$I = nde \qquad (1)$$

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View of high-pressure vessel fabricated at Eddystone showing pressure cylinder withdrawn for loading

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(n is number of electrons produced per sec per unit distance; e is electron charge) (*5*, *6*). In this relation the current is not a function of insulator thickness as long as there is no measurable gamma attenuation.

The magnitude of the Compton current can be estimated by substituting in Eq. 1 $n = \mu N_0$. [μ is gamma-ray attenuation coefficient of the insulator for scattered photons; N_0 is rate of photon incidence (photons/sec).] For an appropriate average value of d we use $d_{avg} = (R \cos \theta)_{avg} = R_{avg}(\cos \theta)_{avg}$ where R is average Compton electron range, and θ is angle between the electron path and the normal to emission and collection surfaces. The current then is given by

$$I = (R \cos \theta)_{avg} \mu N_0 e \qquad (2)$$

For any given gamma energy, the current produced by the photons will be approximately the same in all small-atomic-number materials. By substituting the following numerical values one can use Eq. 2 to calculate the current from a completely enclosed 10-mc Co^{60} source: $(R \cos \theta)_{avg} = 0.136$ gm/cm²; $\mu = 0.056$ cm²/gm; $N_0 = 7.4 \times 10^8$ photons/sec. This substitution gives a value for the current of 1 $\mu\mu$a.

Since Compton electrons have high energies, they produce high potentials. For example the mean Compton-electron energy from Co^{60} gammas is 550 kev and the corresponding range in a polystyrene insulator is 2 mm. In a thick insulator the current is the sum of the individual electron movements and the potential difference is the sum of individual energy contributions required to move an electron from source to collector. Since 550 kev corresponds to a range of 2 mm, a potential of 5×550 kv $= 2.75 \times 10^6$ volts can develop over 1 cm.

Detector operation. In our detector photons and electrons travel to a central collector made of lead to ensure efficient gamma absorption. The gamma absorption is essential because gammas that penetrate the collector produce a reverse current by means of their Compton electrons. The collector becomes negatively charged and forms the negative electrode of the circuit. A thin grounded film on the outside of the insulator serves as the positive electrode.

The same considerations that determine the magnitude of the current for the battery are valid for the detector. One can also use Eq. 2 to calculate the current density from a Co^{60} gamma beam. For a 1-roentgen /sec flux, $N_0 = 1.6 \times 10^9$ photons/cm²/sec and the current density is 2 $\mu\mu$a/cm². Our experiments with the detector have confirmed this theoretical result (*7*, *8*).

Gamma Battery

Application of our theory to a high-voltage, low-current power source shows that a 1,000-curie Co^{60} source that is surrounded by a 2-cm polystyrene insulator gives a current of 0.1 μa.

When the battery is operated at 500 kv (10% of theoretical open-circuit voltage), the power is 50 mw, and the conversion efficiency for absorbed gamma energy is 7%.

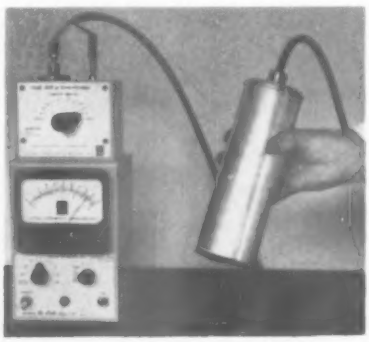

FIG. 3. SMALL DOSIMETERS are powered by gammas that they measure. In left instrument, voltage difference is proportional to total absorbed dose. In right one, current yielded gives absorbed dose rate

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Since this insulator absorbes 5% of the gamma energy, the total efficiency is 0.35%.

Absorption of a greater fraction of gamma rays will increase the total efficiency if the output voltage is raised accordingly. On the other hand, for a given output voltage the insulator thickness can be increased to reduce leakage with only a small drop in efficiency; the drop corresponds to the gamma absorption in the insulator.

Gamma Detector

The essential features of our radiation detectors are shown in Fig. 2. Although the physical principles are quite different from those in an ionization chamber, the measurement technique is similar since a current proportional to the radiation intensity or a voltage difference proportional to the total dose develops. The essential differences from an ionization chamber are these: the detector does not need initial voltage or power; the detecting element is solid not gaseous; the detector can be made directional; there is no variation of sensitivity with dose rate; the energy response can be varied.

Our working model contains a lead absorber, a Lucite insulator and a copper foil outer cover (Fig. 3). Lead gives efficient gamma-ray absorption, and copper provides a thin, easily workable foil. The 1-cm-thick Lucite insulates well enough to permit gamma charging to moderate voltages and to hold the charge for hours if necessary before it is read. In use the cable can be removed and replaced by a protective cap. This detector has a sensitivity of ~1 volt/roentgen. The final potential can be read easily on an electrometer, a pocket fiber voltmeter or vacuum-tube voltmeter (*9*).

We also designed a second model for monitoring reactor gamma rays (Fig. 3). It contains a 4-cm-diameter, 12-cm-long cylindrical lead absorber, paraffin insulator and thin aluminum cover. The current output is 71 $\mu\mu$a in a 1-roentgen/sec gamma flux; the output is essentially independent of gamma energy for a reactor gamma spectrum and is unaffected by reactor neutrons (*10*).

Because our working-model dosimeters are small, not all of the gamma rays are stopped in the absorber. Gammas that penetrate the absorber produce in the insulator

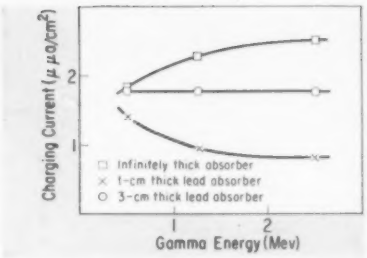

FIG. 4. GAMMA CHARGING CURRENT depends on absorber thickness and gamma energy. Curves are calculated for 1 roentgen/sec

on the side away from the source a reverse electron current that reduces the sensitivity of the unit. In addition, the fraction of primary gammas that reach the second insulator is determined by the energy-dependent attenuation-coefficient of the absorber. Therefore the energy response becomes a function of absorber thickness. Figure 4 shows the current variation with gamma energy predicted by theory for different absorber thicknesses. The curve for an infinitely thick absorber is the theoretical charging curve. We calculated the other curves from this one by subtracting the reverse current, which is the sum of the emergent primary beam and gammas singly scattered in the absorber. We have assumed that these scattered photons are half as effective in producing a current as the primaries are. You will see from Fig. 4 that one can design a response to be independent of photon energy (flat, horizontal curve) or to discriminate against either high- or low-energy photons by choosing the particular absorber thickness that is the most appropriate to the purpose.

* * *

This work was supported by the Brazilian National Nuclear Energy Commission.

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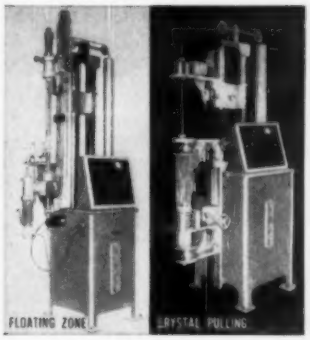

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Neutron-Source Calibrations: A Review

By EDWARD J. AXTON, *National Physical Laboratory, Teddington, Middlesex, England*

Many laboratories throughout the world have established standard neutron sources and have calibrated their strengths in absolute terms. As the figure shows, periodic international comparisons of these standards show a steady improvement in the measure of agreement achieved between the various laboratories.

Presentation of Data

The results of three recently published comparison experiments (*2–4*) are presented in the table. Inconsistencies in the results may be due to errors of measurement or to actual changes in source strength. To iron out these discrepancies and to obtain a best estimate of the errors in the absolute calculations, the figures in Columns 8–10 have been subjected to a least squares analysis. The analysis is restricted to those sources that have been calibrated to an accuracy of ±3% or better. The over-all spread of the values is 3.8%.

The degree of agreement between two laboratories A and B in their estimates of neutron-emission rate can be expressed in terms of the quantity $p = (Q_A/Q_B) \times R(B/A)$ where Q_A and Q_B are the emission rates assigned by the laboratories to their own standard sources as a result of one or more absolute measurements, and $R(B/A)$ is the ratio, determined subsequently in a relative experiment, between the two emission rates. p is then the value which would be assigned by laboratory A to a source of value unity according to laboratory B. The deviation of p from unity is a measure of the accuracy of the determinations of Q_A and Q_B, combined with the precision of the measurement of the ratio $R(B/A)$. Only if this precision is great can the value of p (relative source strength) be used to show up systematic errors in Q_A and Q_B.

Relative source strength (p) for a number of standard sources have recently been published after three independent comparison experiments (*2–4*). The laboratories involved and relevant details of sources and measurements are listed in the table.

From time to time slight alterations are made in preferred values to be adopted for neutron-capture cross sections (see Page 114–*5*) and other factors involved in the absolute calibrations. Thus amended values for some of the standard sources appear occasionally in the literature. Although these numbers may not be the latest preferred values, they serve to provide a common basis for this discussion. The published relative source strengths (p) for the various sources have been amended, where necessary, to conform with the Q values listed in the table.

Interpretation of Data

Since the scales of Columns 8, 9, 10 are arbitrary, it is necessary to normalize each set of values to a common scale for comparison purposes. It is immediately evident that the data do not form a consistent set. (For example compare Switzerland and Harwell on the Swedish and Harwell scales.) Hence there are no obvious conversion factors with which the scales can be linked. Since the discrepancies are, in

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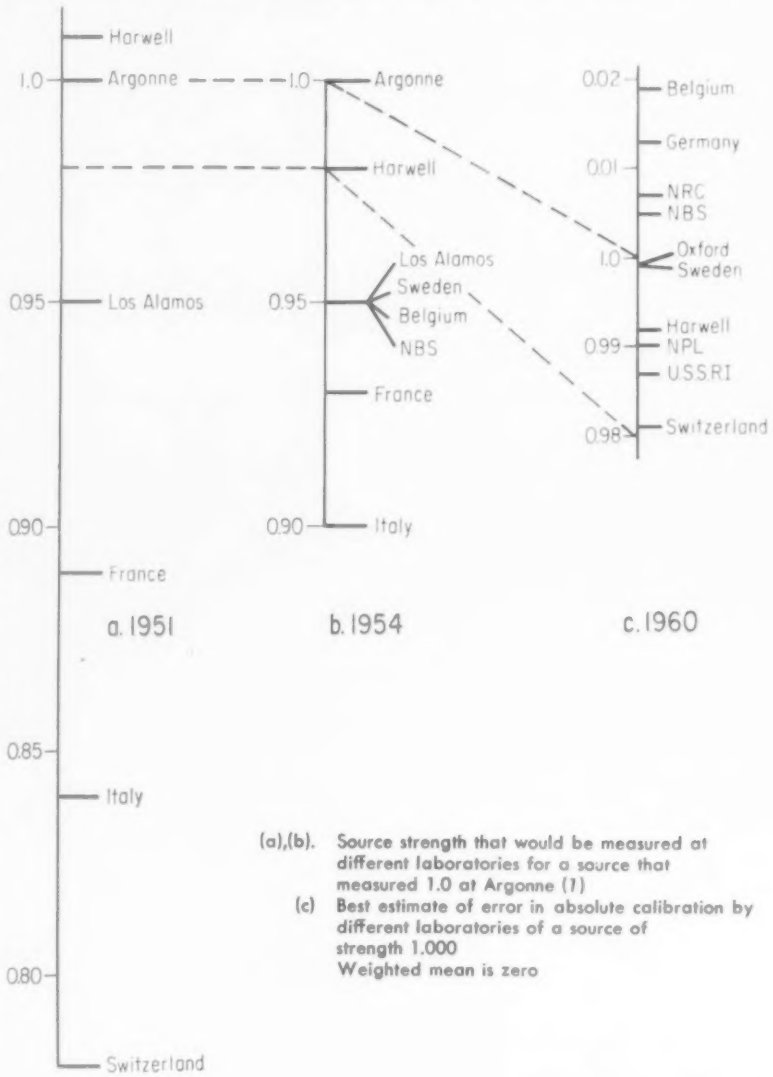
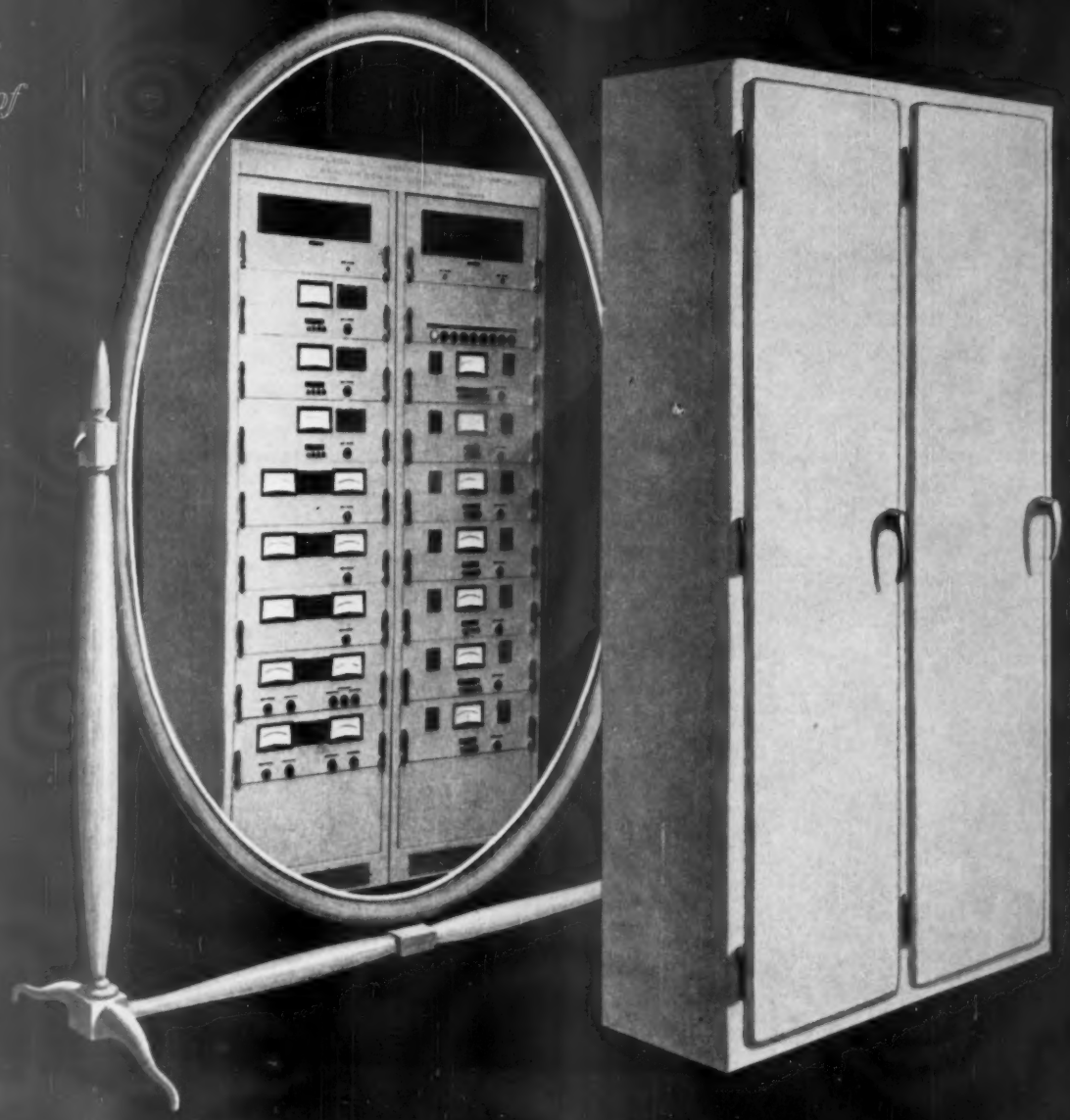


(a),(b). Source strength that would be measured at different laboratories for a source that measured 1.0 at Argonne (*1*)

(c) Best estimate of error in absolute calibration by different laboratories of a source of strength 1.000
Weighted mean is zero

A Step Ahead of the State of the Art in Reactor Controls



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Neutron Calibrations

This article starts on page 90

fact, comparable in magnitude with the apparent errors in the absolute calibrations, it is not possible to establish relations between the latter with any degree of certainty. This state of affairs may be due simply to errors in the comparison measurements although in some cases the inconsistencies seem to exceed those that one would expect from such errors. Alternatively, it may be due to errors in the corrections applied for time-dependent variations of neutron emission. (All radium-based sources must be corrected because of the slight change resulting from the radioactive decay of radium. Ra-Be(α,n) sources are further corrected for polonium growth, but often the age of the radium is just not known accurately enough.) Further changes in neutron output may arise as a result of the mechanical dis-

Three Comparisons of Standard Neutron Sources

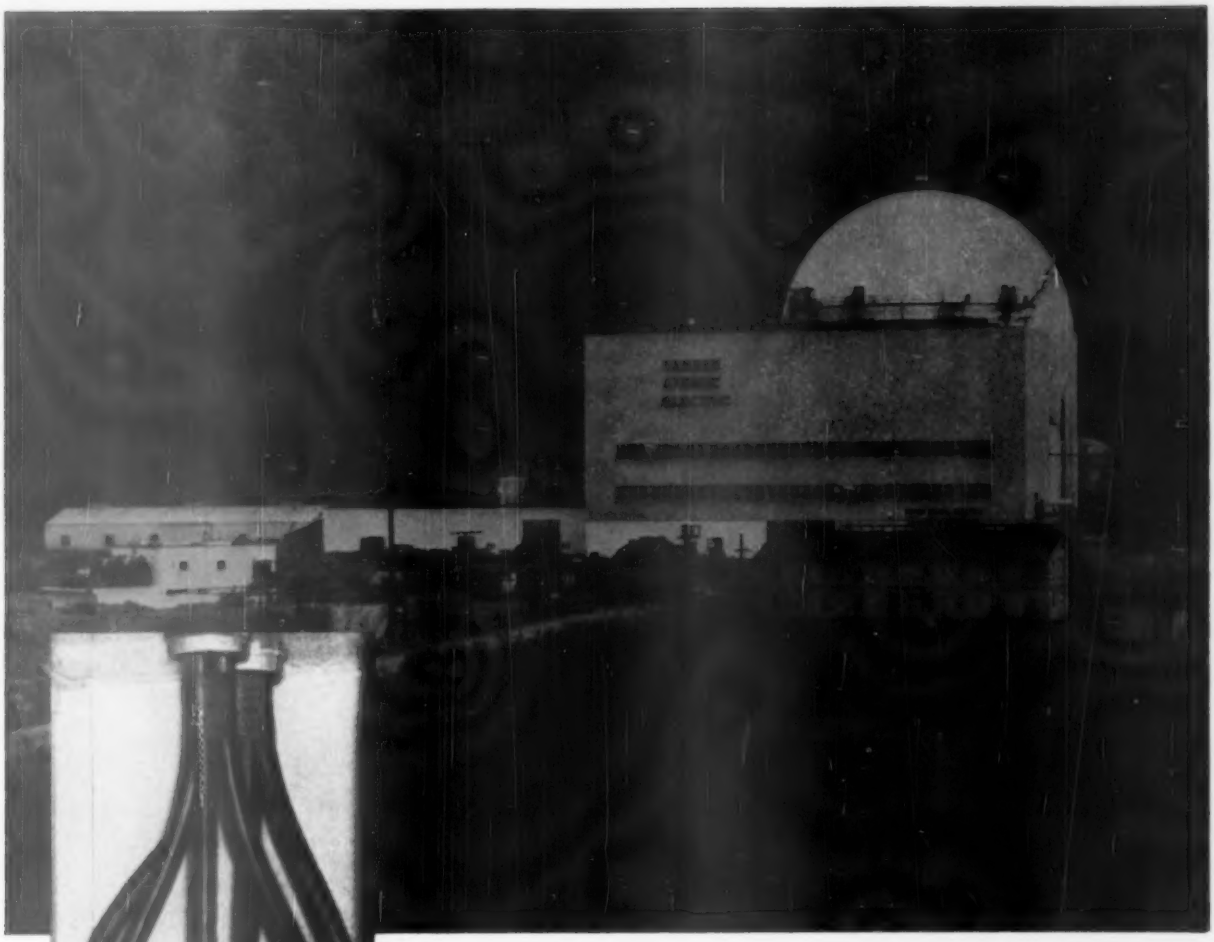
Laboratory	*Type of source*	*(Q) Output (10^6 n/sec)*	*Reference date*	*Accuracy of absolute value (%)*	*Method of absolute calibration*	*Ref.*	*Relative source strength, p (see text)* Harwell (Richmond 1957)	Sweden (Larsson 1958)	NRC (Geiger 1960)	*Best estimate of error of absolute value (%)*
NBS, U. S. A.	Ra-Be(γ,n)	1.186	1955	±3	(1) Water bath. Absolute counting of boron reactions	7	1.006	1.016	1.009	+0.5
					(2) $MnSO_4$ bath. Absolute counting of Mn^{56}	8				
Oxford, U. K.	Rd-Th-D_2O(γ,n)	0.0621	5/25/55	±1.6	(1) Absolute counting of associated photoprotons	9	*1.000*			−0.1
					(2) $MnSO_4$ bath. Absolute counting of Mn^{56}	10				
					(3) Counting of recoil protons	11				
Harwell, U. K.	Ra-Be(α,n)	9.04	3/51	±1.6	As for Oxford source		0.996	0.989		−0.8
NPL, U. K.	Ra-Be(γ,n)	0.1615	7/59	±2	$MnSO_4$ bath. Absolute count- of Mn^{56}	12	0.991		0.979	−1.0
ABA, Sweden	Ra-Be(α,n)	2.65	10/54	±2	(1) Absolute counting of alpha particles from $H^3(\alpha,n)He^4$	13		*1.000*	0.992	−0.1
					(2) Water bath and gold foil. Absolute counting of Au^{198}	14				
					(3) H_3BO_3 bath. BF_3 counters	14				
UMHK, Belgium	Ra-Be(α,n)	7.87	12/52	±2	Water bath and gold foil. Absolute counting of Au^{198}	6	0.997	1.027	1.012	+1.9
PTB, Germany	Ra-Be(α,n)	1.95	8/58	±2	Water bath and gold foil. Absolute counting of Au^{198}	15			1.006	+1.3
NRC, Canada	Ra-Be(α,n)	3.208	7/58	±1.5	(1) $MnSO_4$ bath. Absolute counting of Mn^{56}	16			*1.000*	+0.7
					(2) Counting of Na^{22} produced in $F^{19}(\alpha,n)Na^{22}$ reaction	17				
Basle, Switzerland	Ra-Be(α,n)	1.518	4/55	±2.8	Water bath and gold foil. Absolute counting of Au^{198}	18	0.979	1.001		−1.9
Moscow Institute of Physics, U. S. S. R.	Ra-Be(α,n)	5.96	6/51	±3	Graphite stack. "Negative" gold foil source. Absolute counting of Au^{198}	19		0.995		−1.3
Joint Institute of Nuclear Research Dubna, U. S. S. R.	Ra-Be(α,n)	0.486	3/52	±7	$MnSO_4$ bath. Absolute counting of Mn^{56}	20		0.992		
Los Alamos, U. S. A.	Ra-Be(α,n)	6.07	8/44	±5	H_3BO_3 bath. Absolute counting of boron reactions	21	0.999			
ANL, U. S. A.	Ra-Be(α,n)	5.5	10/44	±7	H_3BO_3 bath. Measurement of boron reactions	22	1.063			

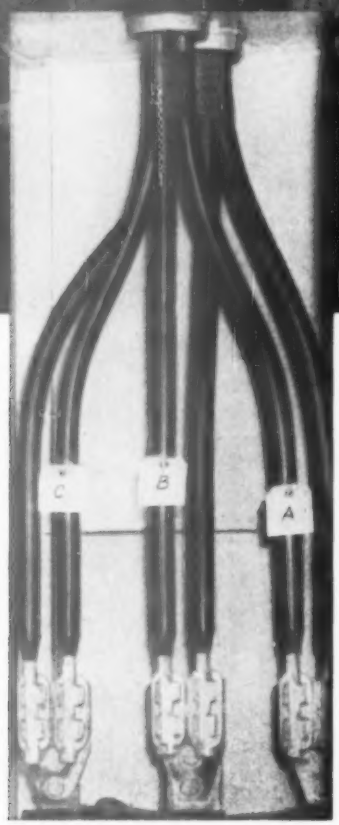
How the Comparisons Were Made. The Harwell data (*2*) (Column 8) are derived from a direct comparison between the Oxford, Durham, U. S. National Bureau of Standards (NBS) secondary, Swiss, and Harwell sources. The comparison was based on the amount of radioactive Mn^{56} produced by each source in turn when mounted at the center of a volume of concentrated aqueous solution of manganese sulphate. In addition, measurements were made on a Los Alamos Pu-Be(α,n) source that had been compared with the Los Alamos Ra-Be(α,n) standard and on an Atomic Energy of Canada Ltd. (AECL) Ra-Be(α,n) source which had been compared with the Argonne Ra-Be(α,n) standard. Also the Swiss source had been compared with the Belgian source. The Durham absolute calibration, which will be based on the amount of helium produced in the Be^9(γ,n)$2He^4$ reaction, is not yet complete. However, the Durham source has been adopted as the National Physical Laboratory (NPL) standard (NPL source in the table) and has been calibrated by absolute counting of manganese activity (*12*).

The Harwell figure has been amended to conform with the *Q* value listed for the Harwell source; this value having been adopted as a result of Richmond's work. Also a slight amendment was made to the Swiss figure to conform with the *Q* value listed for the Swiss source.

The Swedish experiment (*5*) (Column 9) consisted of a direct comparison between the Swedish, NBS secondary, U. S. S. R., Harwell, Swiss and Belgian sources. The method was to compare the integrated neutron flux in a bath of water or dilute boric acid, BF_3 counters being used for the measurements. In addition, the Swedish source was compared with the Russian sources in Moscow and with the Belgian source in Brussels.

For the National Research Council comparison (*4*) (Column 10) the NRC source was compared directly with (a) the Swedish source at Stockholm, (b) the Belgian source at Brussels, (c) the German source at Braunschweig and (d) the NBS secondary source at Ottawa. The NRC source was also calibrated at the National Physical Laboratory by absolute counting of manganese activity. The NPL value has been raised slightly due to a subsequent change in the interpretation of the results of the NPL calibration. This brings the figure into line with the NPL figure in the Harwell column. Also the Belgian figure has been raised slightly to conform with the *Q* value listed in the table, allowing for the increase due to polonium growth (*6*).





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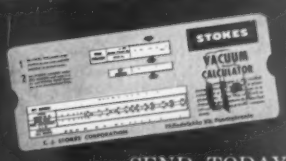

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Neutron Calibrations

This article starts on page 90

turbance of materials comprising the source.

Most of the sources are either photo-neutron or alpha-neutron sources involving radium and beryllium. The energy spectra of the sources are not known accurately; the average and maximum energies of the alpha-neutrons are considerably higher than those of the photo-neutrons, so that additional corrections are necessary for fast-neutron losses in the absolute calibration of the former. Also, optimum dimensions for apparatus depend on neutron energy.

Best Estimate

To obtain the "best" estimate of the errors in the absolute calibrations, the following method has been adopted. Values x_1, x_2, etc. are assigned to the errors made by each laboratory in its absolute calibration. A large number of equations can then be obtained from the data, of the type $x_r - x_s - \delta_{r,s} + \delta_{r,s} = k_{r,s}$ where $\delta_{r,s}$ is the error made by laboratory r carrying out a comparison measurement on source s. (The Los Alamos, Argonne and U.S.S.R II sources were omitted in view of the rather large errors in the absolute calibrations.) The equations are then weighted according to the standard errors of the measurements, and a solution is obtained by a least-squares method to give the most probable values for the x's. The equation involving a given pair of sources is given a weight proportional to the reciprocal of the square of the standard error (σ) in the measured ratio of the emission rates of the two sources as estimated by the various experimenters. On the Harwell scale $\sigma = \pm 0.5\%$ for sources of similar neutron spectra (for example, two α,n sources or two photo-neutron sources). The error was increased to $\pm 1.0\%$ for dissimilar sources, to cover additional errors in estimates of fast-neutron losses. For the Belgian source error was further increased to 1.25% since comparison was indirect.

On the Swedish scale $\sigma = \pm 0.8\%$ with the exception of the NBS figure ($\pm 3\%$) since the NBS source was the only photo-neutron source. On the NRC scale each comparison was carried out at a different laboratory. The estimated standard errors in the ratio between the stated source and the NRC source are as follows: Sweden $\pm$ 0.8%; Belgium $\pm$ 0.12%; Germany $\pm$ 0.3%; NBS $\pm$ 1.0%; NPL $\pm$ 0.6%.

The most probable values for the x's are shown in Column 11 relative to a mean of zero weighted according to the accuracy shown in Column 5. Column 11 thus represents the best estimate that can be obtained of the errors made by each laboratory in the absolute calibration of its own source. It will be realized that the solution is not exact, since each value of x has a standard error that can be calculated only with considerable difficulty. It is sufficient to say that the uncertainties are such that the true errors in the absolute calibrations are masked by errors arising in the comparisons.

This difficulty will probably remain as long as Ra-Be(α,n) sources are retained as standards. The radium photo-neutron source makes a more stable standard but suffers from the smaller neutron emission per curie of radium and the greater gamma background. The plutonium-beryllium alloy (α,n) source and the plutonium fission source would make stable standards for long term comparisons, the fission spectrum of the latter source being of particular advantage for many applications. With more stable sources and improved techniques it should be possible to obtain greater precision in comparison measurements and thus to shed more light on the systematic errors inherent in the absolute calibrations.

* * *

This paper was prepared as part of the program of work of the National Physical Laboratory and is published with the permission of the Director.

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Coated-Particle Fuels—Promise and Problems

The nuclear industry, ever alert for promising new reactor fuels, is paying close attention to coated-particle systems—which promise high-temperature operation, inexpensive fabrication and good neutron economy. A close look reveals problems as well as promise, but long-term development programs such as that sponsored by AEC at the Battelle Memorial Institute should make quantitative some qualitatively attractive features.

Here's what coated-particle fuels are like: Small spherical particles of fuel, comparable in size to common table salt, are coated with an impervious layer of a ceramic material in a vapor-phase coating process. The coating thickness is chosen great enough not only to trap all fission recoils within it but so that a layer of undamaged material remains to contain fission gases and other fission products. The individually coated fuel particles are then evenly dispersed in a matrix material such as graphite. The dispersion can be conveniently and economically shaped into reactor fuel elements of various shapes and sizes by simple mass production techniques.

One advantage of this type of fuel is that it seems to be possible under certain conditions to contain fission products nearly completely. Fission recoils cannot escape, and diffusion through the ceramic coating is very slow even at high temperatures so that as long as the coating remains intact, fission-product loss is small. Consequently, release of fission products will occur only if coating failure occurs. Such failure will not occur readily, because the coating is strong, and the spherical shape ideal for resisting internal pressure, so that such particles have a high resistance to cracking. Furthermore, thermal stresses are low in the particle coating because the particles are small.

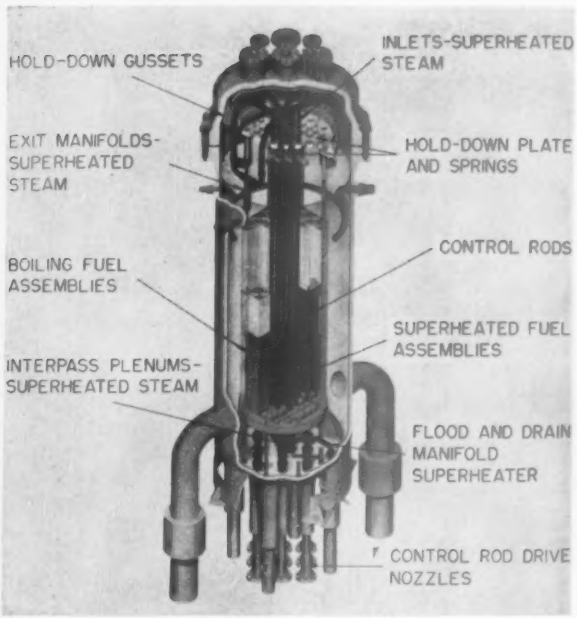
Coated particle fuels have other advantages as well. They can be made entirely from materials having low cross sections so that the neutron economy of the reactor will be good. Carbon, alumina, beryllia, magnesia, zirconia, silicon carbide, and zirconium carbide are among the many possible coating materials. The coated particles can be dispersed in any suitable matrix—graphite and beryllia are the most promising ones, though one could use any other matrix if desired.

Two developments have made it practical to apply thin and uniform coatings on small particles, using a wide variety of materials as the coatings. These are the development of vapor-phase coating methods, and the use of fluidized bed techniques, or barrel plating, for applying coatings. Up to the present time BMI has coated both uranium dioxide and uranium carbide with alumina, beryllia, and pyrolitic carbon. They have also coated such materials with metals such as niobium and chromium.

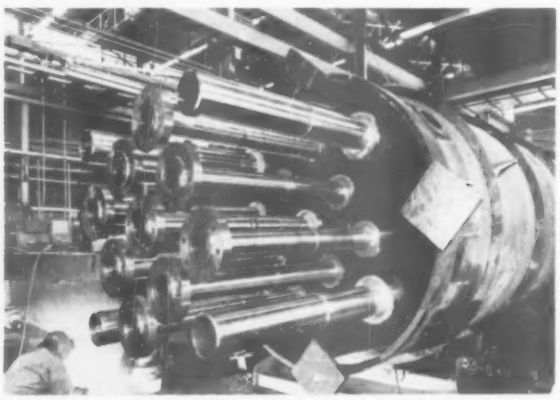
Tests of Coated Fuel

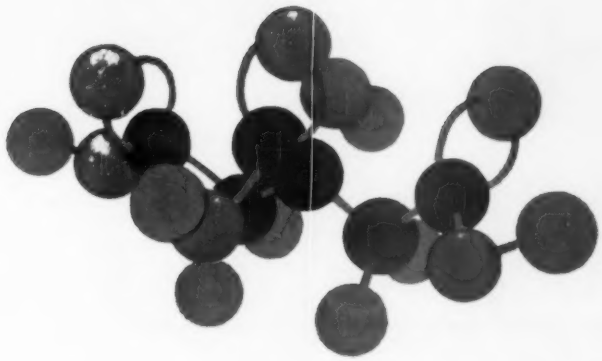
Integrity of the coatings is being studied by leaching, by heating oxide-coated particles in air, or graphite-

Pressure-Vessel Complexity Matches Borax-5 Flexibility



BORAX-5 REACTOR VESSEL, 16 ft high by 5½ ft in diameter and weighing 30 tons, has 2 1/16-in. wall of A212B carbon steel clad inside with type-304 stainless steel. The vessel, fabricated by Nooter Corp. of St. Louis, Missouri, has 40 nozzles (several thermally sleeved) for versatility. Three different cores can be installed in this latest of Argonne's experimental series of boiling reactors: (a) a saturated all-boiling core, (b) a boiling core with central superheater elements, (c) a boiling core with peripheral superheater elements. The boiler fuel elements will consist of UO_2 pellets in stainless-steel tubes; the superheater fuel elements will be UO_2-stainless-steel cermet plates. In operation at 20–40 Mw(th), steam at 600 psi and 489° F will rise from the boiling section, then be pumped downward through half the superheater fuel elements, then up through the other half, from which it will emerge at 850° F. Since superheater section normally will be devoid of water, which otherwise would help as a shield, a 1-in.-thick thermal shield is located inside top head of vessel





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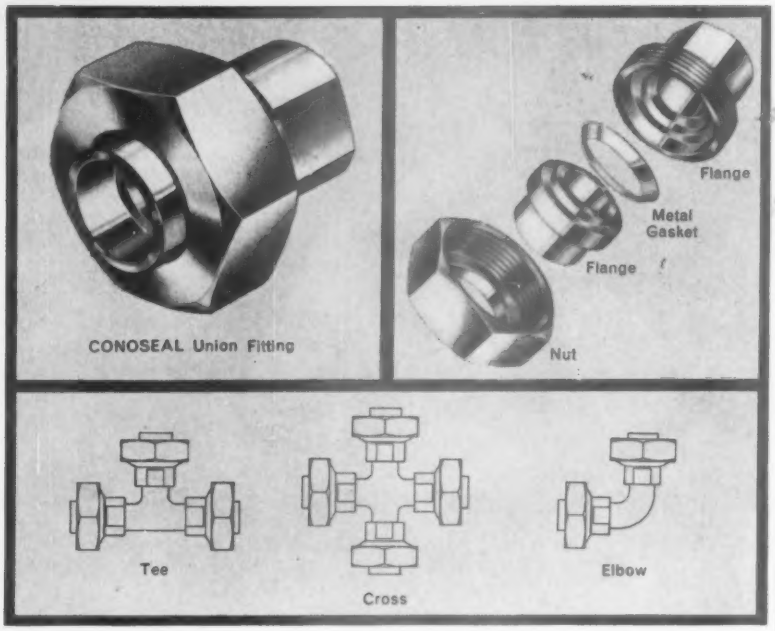

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Coated-Particle Fuels

This article starts on page 96

coated ones in gas followed by leaching, and by neutron activation followed by heating. In all of these tests, properly coated particles have been found to have no detectable defects.

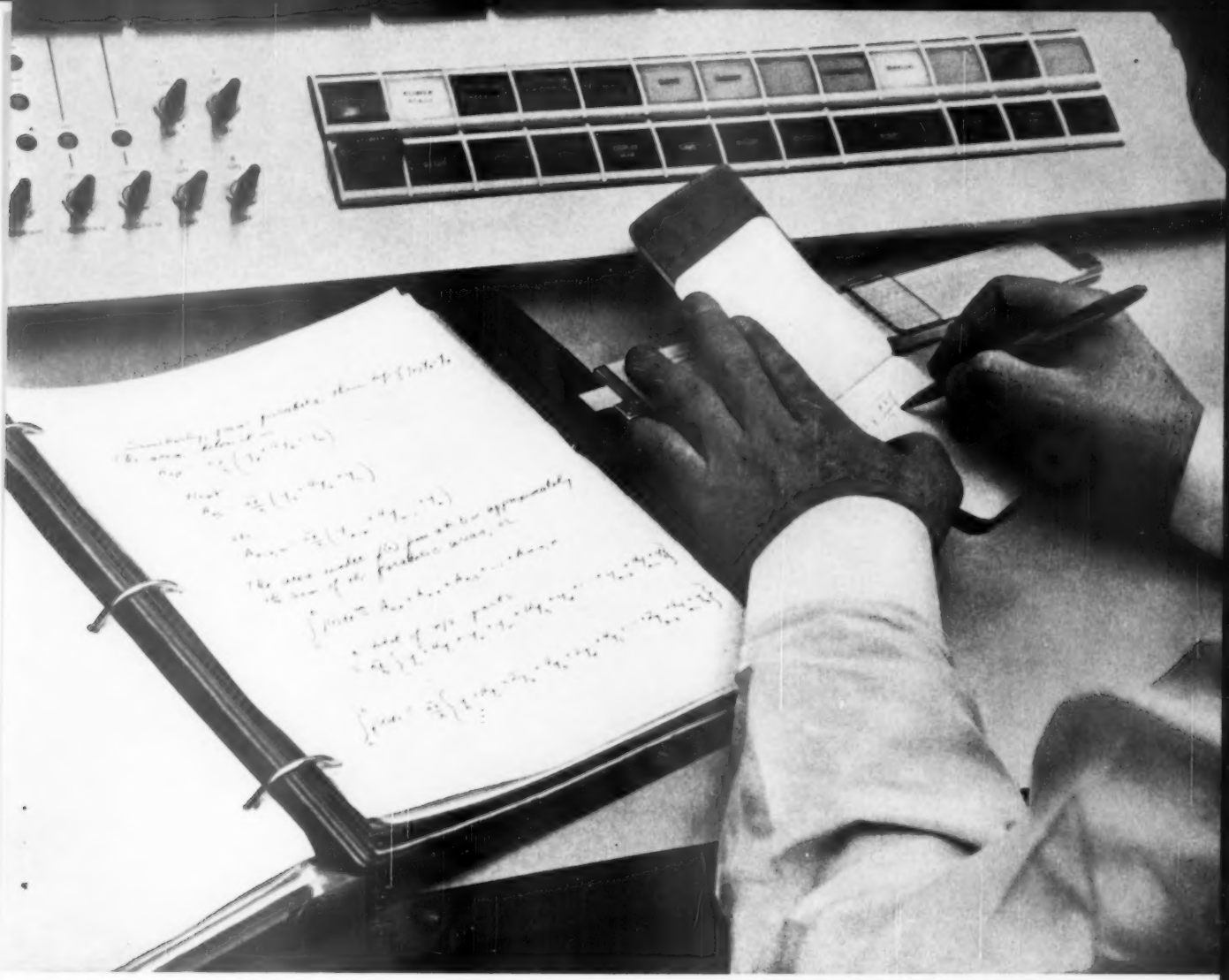
Some of these methods have been used to study coated-particle dispersions in graphite.

The most complete data for this kind of fuel material have been obtained for a dispersion of alumina-coated UO_2 in graphite. The UO_2 particles were 100–140 microns in diameter and these were coated with 40 microns of alumina in a fluidized bed, by the vapor-phase hydrolysis of Al_2Cl_6 at a temperature of 1,000° C. The alumina coatings are very dense, impermeable, alpha alumina, are hard and strong, and transparent. Integrity of the coated particles was demonstrated by the tests previously described.

These coated particles were dispersed in graphite (by National Carbon Co.), to produce graphite balls about $1\frac{1}{2}$ in. in diameter. The absence of damage to the coated particles during graphite fabrication was demonstrated by neutron activation and heating tests.

Irradiation tests have been made on this material. In some low-level radiation studies, a ball was irradiated and heated to temperatures of up to 1,000° C. Fission-gas release rate was monitored continuously, and found to be 10^{-5}–10^{-6} of the rate of fission-gas production.

Another irradiation test was run at high flux, to a total burnup of 5–6% of uranium atoms, while fission gas release was monitored continuously. The initial fission gas retention was extremely good, about 10^{-6}–10^{-9} of the quantity produced depending on the particular fission product isotope. It is believed that this release resulted from minor contamination of the coating by uranium. The release of fission gas increased somewhat as radiation progressed, until the release had reached a level of 10^{-3}–10^{-5} at a burnup of 5–6%. This result suggests that deterioration of some of the coatings had occurred during irradiation, and the cause of this deterioration will be determined from postirradiation examinations which are now in progress.—*Based on information supplied by R. W. Dayton, Battelle Memorial Institute.*



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Repair of the HRE-2 Core

By EUGENE C. HISE and IRVING SPIEWAK
Oak Ridge National Laboratory, Oak Ridge, Tennessee

In April, 1958, soon after Homogeneous Reactor Experiment No. 2 (HRE-2) had achieved its rated power of 5 Mw, a hole formed in the Zircaloy core vessel. Although the hole connected the core and blanket regions, it did not prevent continued power operation with fuel solution in both regions. A program was initiated to determine the cause of the damage, to prevent further damage and to develop repair methods.

It was determined that the fuel solution became unstable when overheated, creating solid or heavy-liquid materials of high uranium concentration. Flow tests were made in a core model to study the behavior of corrosion products and other materials in the upward-flowing fuel stream. It was concluded that solids could accumulate in regions of low velocity or flow separation, become overheated and cause uranium to precipitate. This autocatalytic process could continue up to burnout, melting a hole in the vessel; flow through the hole would then wash away the deposit.

It was further concluded that core-wall cooling could be improved substantially by removing five Zircaloy diffuser plates which acted as flow distributors, by reversing the direction of flow and by patching the hole so that mixing of core fluid into the blanket could be reduced and possibly eliminated. After tools had been developed to perform these tasks, it was discovered that a second hole had been formed during continued operation. This second hole was patched during work that began in March, 1960, and was completed in August.

The conditions under which this work was performed are illustrated in Figs. 1 and 2. The detailed program included inspection, material removal and repair. Each operation was performed with a specially developed tool; each technique is, however, of general interest to maintenance engineers who

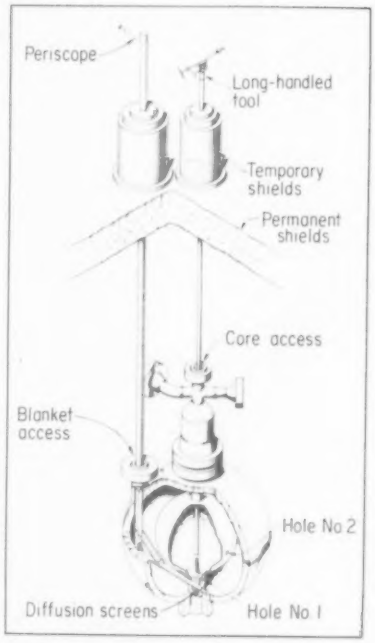

FIG. 1. REPAIR OF HOLES in HRE-2 core vessel was done remotely. Access to core was through 2⅛-in.-diameter flange and to blanket through 3½-in. flange. Workers were on top of shield plugs 17 ft above vessel equator. Radiation level in empty vessel was >100,000 r/hr—much of it as scale or loose particulate matter that grossly contaminated tools

HRE-2 Back on Line

The HRE-2 attained a 5-Mw power level on January 4, 1961, with no indications of the chemical instabilities noted previously. The improvement is attributed to the reversed flow of the fuel solution. The power-time trace of the reactor is now characterized by continuous mild power oscillations. It is believed that the oscillations are brought about by turbulent fluctuations in the homogeneous core, which does not have control rods.

However AEC decided late in 1960 to terminate HRE-2 work and the entire homogeneous program by June 30, 1961 (see p. 31).

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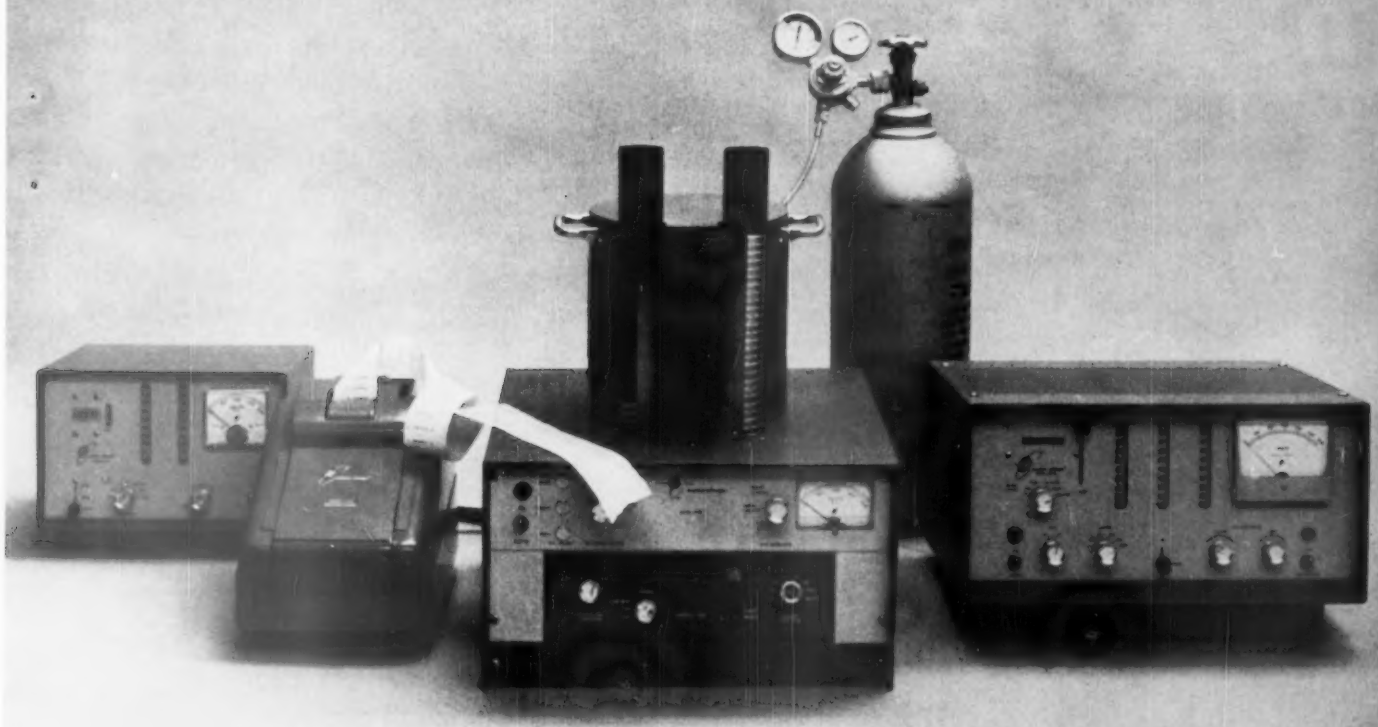

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FIG. 2. PORTABLE STEEL SHIELD for direct hot maintenance of HRE-2 components. Sections of 10½-in.-thick steel slide on rails. Modules (above) contain eccentric plugs, periscopes, lights and openings for long-handled tools

may try to cure sick reactors in the future.

Inspection Operations

For viewing in the core, a ⅞-in.-o.d. by 21-ft-long periscope was developed by Lerma Engineering Corp. (Northampton, Mass). Its optical elements are of cerium-stabilized glass, which after several hundred hours of use shows no appreciable loss of light transmission. The scope has interchangeable objective elements, one of which gives a 180-deg field of vision and the other a 30-deg field of vision at right angles to the instrument axis. Lighting is provided by 500-watt projection lamps caged and mounted on 20-ft-long ¼-in. tubing handles. This instrument provided vision for many mechanical operations and was used to obtain a complete photographic map of the core. Combined with the Questar telescope (manufactured by Questar Corp., New Hope, Pa.), microscopic examination *in situ* was possible.

For operations where vision was essential but space in the access flange could not be spared for lights and a periscope, an external-light-source viewer was developed. This device was used a great deal to view the removal of objects from the core.

In most of the operations performed on the holes, vision from the blanket side was needed to aid in positioning the tools. This was provided by projector lamps and fixed and rotatable mirrors mounted on a frame that could be erected remotely after insertion into the blanket region.

Measurements of the thickness of the Zircaloy core vessel were made by means of an ultrasonic transducer. A manipulator positioned the transducer at preselected points over the entire core surface. It was thus established that corrosion had reduced the core wall from an average of 0.312 in. to 0.300 in. during power operations. Metal losses were greatest (up to 0.040 in.) in regions of uranium deposition.

To obtain the exact dimensions of the two holes, impressions were made with electrically heated thermoplastic blocks. The contaminated plastic blocks were replicated in a hot cell to obtain a clean casting. The replica of the lower hole served as a model to fit the patch; use of the other replica is described further on.

Cutting Screens, Cleaning Core

Saws were devised to cut the diffuser screens loose from the core wall. The operation of the reactor, however, had already burned or corroded these screens loose.

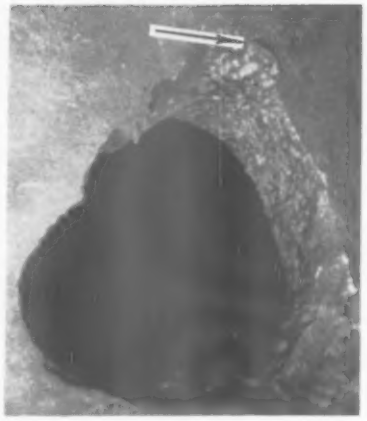

FIG. 3. LOWER HOLE leaked after patching because of piece of Zircaloy screen welded to wall (arrow)

For removal from the vessel, the screens were cut into strips 1½ in. wide with an underwater cutting torch, operated blind. A manipulator positioned each screen vertically and then guided the vertical torch travel. Simple hooks and grapples, mounted on long tubes, raised the strips into a bucket placed just above the access flange. Cutting debris was flushed into a screen filter.

An air-motor-driven wire brush cleaned and descaled the core. This tool, mounted on a manipulator hinged at the spherical center of the core, made consecutive overlapping horizontal passes over the entire core surface.

Patching the Holes

The first hole (Fig. 3), 1½ in. in diameter, was clean and fairly round in appearance so that it appeared to be

The Upper-Hole and How They Patched It

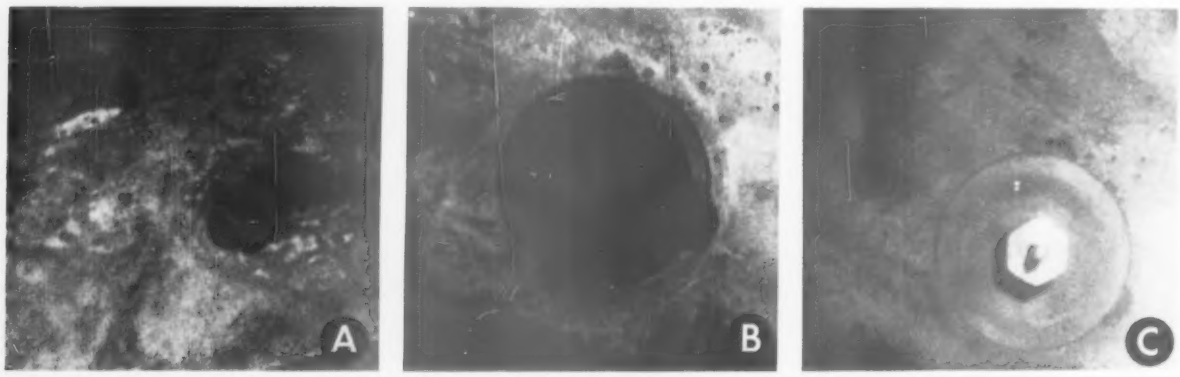

FIG. 4. UPPER HOLE was elongated (A), required rounding (B) before patch was attached (C)

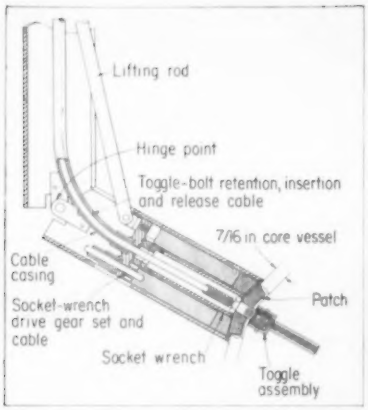

FIG. 5. PATCH-PLACEMENT TOOL inserted toggle assembly through hole and tightened bolt which operator observed with blanket viewer

suitable for patching without additional preparation.

The elongated shape of the second hole (Fig. 4) and surface contamination necessitated preparation before patching. A hook scraped loose deposits away; a hole saw rounded the hole (to provide a precise pilot for positioning the saw, a plastic impression of the hole had been obtained earlier); and then a 24-fluted tapered reamer machined a seat with a 60-deg seating angle for countersinking the patch. Metallographic examination of the specimen removed by the saw from the core wall proved that overheating rather than corrosion was responsible for the hole.

The patch-placement tools performed the final operations (Fig. 5). Each patch comprised a cover plate, gold sealing surface and toggle bolt.

The leak rate across each patch was determined by gravity flow of water from one region to the other. The leak rate across the lower hole was 6 lb/min with a 1.2-in. water head. This is attributed to mechanical interference of a small piece of Zircaloy screen left welded to the wall (Fig. 3). If this produces excessive mixing in future runs, the patch may be reinstalled. The leak rate across the upper hole was small.

Conclusions

Two main conclusions are derived from this work: (1) fluid-fuel reactor maintenance is practical without overexposure to radiation—in no case did exposure exceed weekly tolerance—and (2) detailed inspections and repairs can be made in the core of any reactor type following an unforeseen accident.

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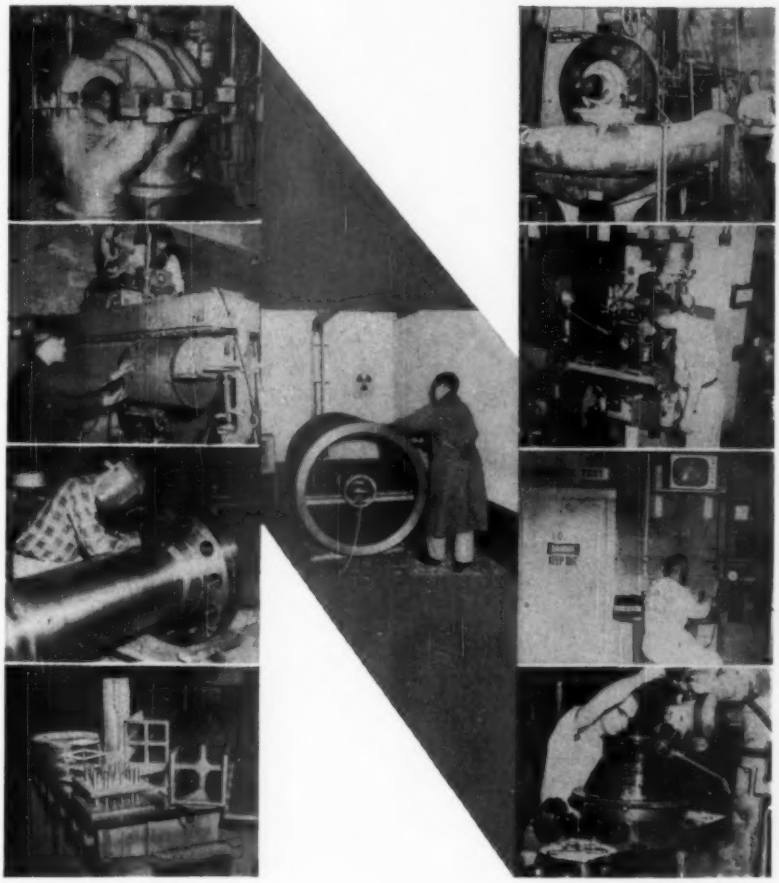

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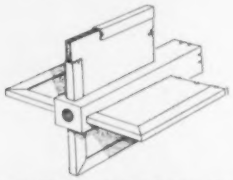
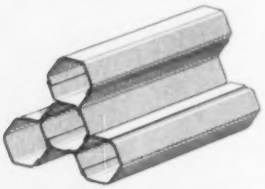
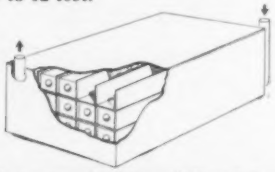


Shut-down Control Rod for Reactors
Assembly of this unit is made by arc welding. All edges of Boral Plate are clad. The center bar is tapped to receive the threaded rod.



Storage Cells for Fresh Fuel
Cells are usually used in assemblies of several fuel units, encased in aluminum or stainless steel cylinders. The Boral shapes should have corner radii of ¾"; length can be up to 12 feet.



Water-cooled Boral-lined Case for Spent Fuel Elements
This Boral-lined aluminum case with egg-crate type separators for the transportation and storage of spent fuel units, is assembled from Boral Plate by arc welding.

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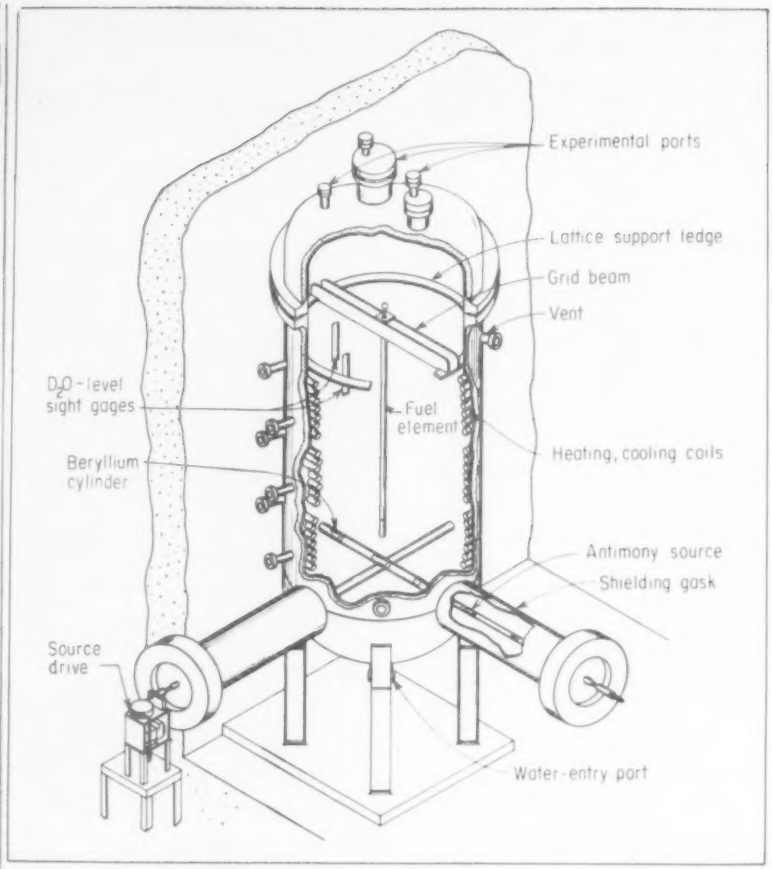


SUBCRITICAL UNIT is designed to provide physics data for heavy-water-moderated power-reactor designs having high moderator temperatures

Pressurized Subcritical Facility

By **E. J. HENNELLY**, *Savannah River Laboratory*
E. I. du Pont de Nemours and Company, Aiken, South Carolina

In a survey of heavy-water-moderated power reactors which du Pont is performing for the AEC, some designs require high moderator temperatures. Because there is little physics data for this reactor type, Savannah River Laboratory has installed a pressurized subcritical experimental facility (PSE).

The PSE (see illustration) has a self-pressurizing tank that is heated to 215° C by steam coils. Neutrons are supplied by five retractable Sb-Be sources (see article on p. 124 for characteristics of these sources). The facility is in a room that also houses an unpressurized subcritical experiment (SE). Thus the PSE can be calibrated in terms of the SE at room temperature.

Pressure Vessel

The pressure vessel is rated at 300 psig. The tank wall is $^{13}/_{16}$-in. carbon steel with $^{1}/_{16}$-in. stainless-steel interior cladding. The internal diameter is 5½ ft, and the overall height, ~13½ ft.

The bottom of the vessel is hemispherical. The elliptical top head is fastened by sixty 1½-in.-diameter bolts through 6-in. flanges. Asbestos gaskets are used on all flanges. A 30-mil cadmium sheet is wrapped around the vertical exterior of the vessel and a 1.25-in. layer of MgO insulation covers the entire tank except at the flanges.

About 400 ft of 2-in. stainless-steel piping, coiled in three sections on the interior wall of the vessel, heats the vessel with steam or cools it with water.

Sb-Be Neutron Sources

The neutron sources are activated by remotely inserting stainless-clad radioactive antimony capsules into permanently-mounted beryllium cylinders (see illustration). The antimony is retracted into lead-filled shielding casks before personnel enter the room. The maximum gamma dose rate at the cask surface is <100 mr/hr.

The source locations in the source tubes were selected to minimize harmonics in the neutron-flux distribution in the tank. One source is located in the center and the other four are on radii 90 deg apart, about halfway between the center and the edge of the tank. The center source is 4–5% stronger than any of the radial sources. Source strength is $\sim 10^{10}$ neutrons/sec. When the tank is filled with D_2O, the radial flux distribution follows a J_0 function within experimental accuracy 50 cm above the plane of the upper source tube. The cadmium ratio of gold pins, 0.060 in. in diameter, is 10^3 at this distance from the sources.

Fuel Failure Detector

A preoperational safety review revealed that the explosion potential of deuterium gas was a possible hazard. This gas might evolve from the uncontrolled corrosion of uranium metal in the event of a sheathing failure. A deuterium analyzer was therefore installed for early failure detection.

The analyzer sensor is a Gow-Mac thermal conductivity bridge, which measures the difference in thermal conductivity between two gas streams. In the event of a fuel failure, one stream would contain deuterium from the PSE and the other would serve as a deuterium-free reference. Tests showed that the device is capable of detecting as little as 5 ppm of D_2 in the gas stream at a flow rate of about 1 ft^3/hr.

Materials Selection

Materials for measuring neutron flux at 215° C must resist corrosion, be easily activated, have reasonably uniform composition and include resonance, $1/v$ and fission detectors.

Gold foils and pins were used for long irradiation times and for mapping a large number of points. Indium foils were used at temperatures <100° C, but became too soft above this temperature.* An In-Pb alloy containing 20 w/o In was used in up to 215° C. These foils were 15 mils thick and ½ in. in diameter. A sintered mixture of 15.7 w/o In_2O_3 in aluminum was suitable at high temperature when inserted in a vertical air-filled thimble in the PSE, but disintegrated to a powder in contact with water at 215° C. "P-metal," a commercial alloy containing 72 w/o Mn, 18 w/o Cu, 10 w/o Ni, was used successfully in 215° C water.

For short irradiations, only the Mn was activated appreciably; these foils were 5 mils thick and ½ in. in diameter. Zr-U^{235} alloy foils made from a rolled section of PWR fuel element had satisfactory corrosion resistance, but were nonuniform and required extensive calibration. They exhibited about the same activity as the P-metal foils. Cadmium covers withstood corrosion satisfactorily; thin, yellow film formed after several exposures to water at 215° C, but this was not troublesome.

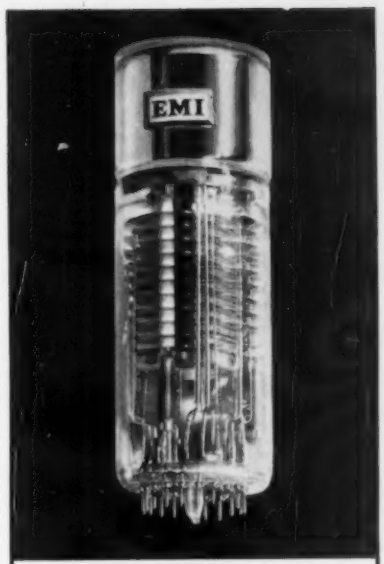
A 2-mil Teflon tape (Temp-R-Tape-C) was used to attach the foils to aluminum holders. This material also seals a foil against water at 215° C for an experiment lasting about 1 hr. It is thin enough to have negligible effect on foil activation. Thin aluminum foil is used for longer exposures or when water exclusion is not a requirement.

Aluminum alloys and stainless steel are used as structural materials. Aluminum is used for foil holders and in regions requiring low neutron absorption. Permanent fixtures are stainless. However, the stainless steel in the vapor space of the PSE, most of which is work-hardened, has corroded. It is believed that the steam leaches chloride ions from the asbestos gaskets, and these ions catalyze the steel corrosion. The stainless sheaths on the thermocouples became so brittle that they broke. A metallic gasketing material is being considered as a replacement. The corrosion on the walls of the vessel that surround the vapor space is widespread but not serious; no corrosion is visible on the walls that contain the liquid phase.

* * *

This article is based on work performed under contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

* Indium and Pb-In foils made by Indium Corp. of America, Utica, N. Y.; sintered In_2O_3-Al foils by Sintercast Corp. of America, Yonkers, N. Y.; P-metal by Metals and Controls Corp., Attleboro, Mass.; Temp-R-Tape-C by Connecticut Hard Rubber Co., New Haven, Conn.



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NPR Uses Carbon Steel

By H. R. KOSMATA, *General Electric Company, Hanford Atomic Products Operation, Richland, Washington*

The New Production Reactor at Hanford will be the first full-scale, water-cooled reactor to use carbon (mild) steel for out-of-pile sections of the primary-coolant loop. The decision to use carbon steel was based on an evaluation program that indicated: (a) Carbon-steel corrosion and decontaminability are acceptable; the primary risks are the chance of poor operational control or accidental damage during decontamination. (b) Replacing stainless with carbon steel is saving ~$10-million. The present estimated NPR cost is $145-million.

Early Use of Stainless

Since the carbon and stainless steel prices are well known, one might ask why this substitution was not made sooner—why was stainless necessary at all in water-cooled systems?

Production reactors. The first (and current) Hanford reactors were cooled by treated river water on a once-through basis with discharge to the river. The natural-uranium fuel made neutron economy paramount. For this reason aluminum was used for both process tubes and fuel cladding, and water chemistry was oriented toward minimum aluminum corrosion. The water *p*H required was ~7, which is fairly corrosive to carbon steel. Therefore, the material used for much of the out-of-pile piping was 18-8 stainless.

Savannah River also resolved the incompatibility of carbon steel and aluminum by using stainless steel. Since these were the first major nuclear plants, it may explain why stainless steel became the "standard" material for the nuclear industry.

First nuclear power plants. Subsequent water-cooled reactors were primarily Navy power plants using enriched-uranium fuel and stainless steel and zirconium alloys as in-pile materials. This might have allowed changes in out-of-pile materials; however, high reliability and short schedule dictated the use of "proven" stainless steel.

The Navy instigated, however, a development program at Bettis and Arco in conjunction with their S1W (Nautilus prototype) and A1W (aircraft carrier) projects. The objective was to obtain data that might indicate the technical feasibility of using carbon steel as a primary-loop material. Their goals were cost reduction, conservation of essential materials (nickel) and simplified procurement. Further, there had been indications of stress cracking in stainless systems.

During this period ('53 to '56), the first civilian nuclear power plant (Shippingport) was built. It too employed stainless steel for the loop material, primarily because the schedule did not allow the designers to wait for results from the experimental programs.

Hanford Materials Program

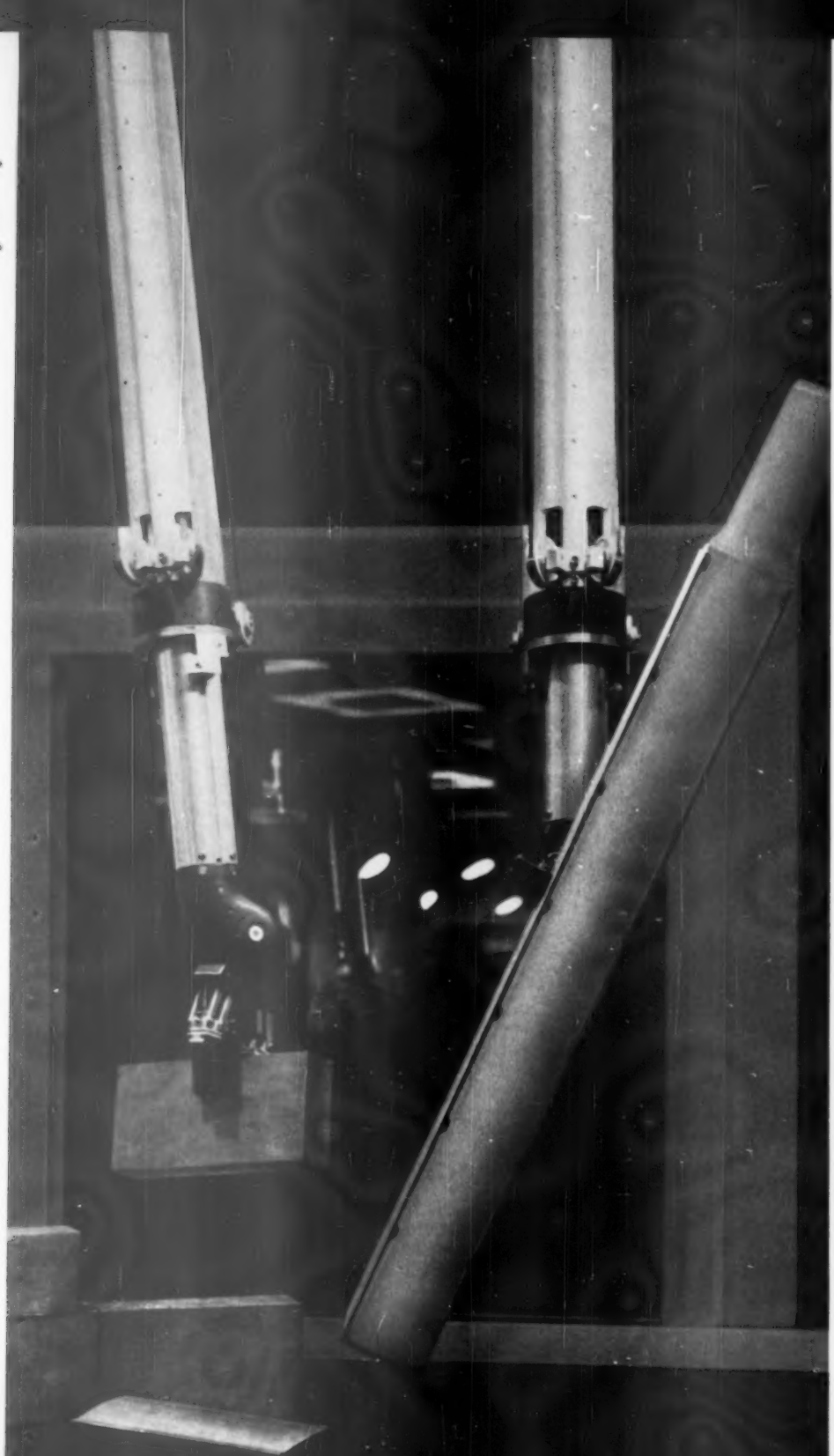
Meanwhile, dual-purpose reactor systems were being studied at Hanford. The operating temperatures for such systems were beyond those at which aluminum could be used but, with enriched fuel available and economically feasible, the fuel cladding and process tubes could be steel or zirconium alloys. With water chemistry no longer

The New Production Reactor

Previous Hanford production reactors have had one-pass primary coolant systems with the water discharged to the river. The NPR employs a recirculating primary coolant operating at temperatures and pressures suitable for power production. In the event that the need for weapons plutonium should end, the reactor could be converted to power-only operation.

In the first operational stage, virtually all of the reactor heat will be dissipated to the river. For power, steam would go to turbines.

Because this reactor is "convertible" from solely plutonium production to byproduct electrical production, the design level of the primary loop is 600° F. For this reason, in-pile materials (process tubes and fuel cladding) will be zirconium alloys. This means the water chemistry can be maintained at high pH levels. Since this reactor requires large quantity of high-pressure piping (~3.5-million pounds), the cost incentive was very high.



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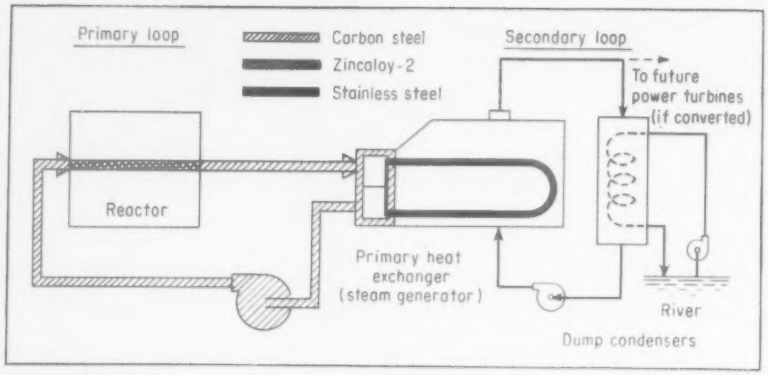


MATERIAL SELECTION for NPR primary coolant loop. Reactor heat will initially be "dumped" into river, but steam can eventually be diverted to turbines

dictated by aluminum, it became possible to consider other than stainless steels for the out-of-pile primary-loop.

An extensive program was initiated at Hanford to investigate the out-of-pile materials. The primary tools in this program were four loops in one of the newer production reactors, each having zirconium-alloy process tubes and one having carbon steel and three, stainless-steel out-of-pile piping.

Major problem areas. It was time to consider a long-unanswered question: Why are the material requirements of nuclear power plants different from those of conventional steam power plants, which have always used carbon steel successfully?

Two basic differences between these systems have caused nuclear designers to hesitate: (1) where the conventional plant strives to eliminate oxygen, the nuclear plant generates it due to radiolytic breakdown of the water; and (2) activation of corrosion products in a nuclear plant results in general radioactivity of the entire coolant system. This means greatly increased maintenance costs unless chemical decontamination can reduce the system activity to feasible working levels. Here lies the significance of the second difference—decontamination means an occasional intentional corrosion of the pipe walls. Prior to test-loop operation, the magnitude of these problems was not known.

Oxygen generation. The Navy program made good progress in establishing optimum water conditions and in investigating the magnitude of the free-oxygen problem. They recommended a pH of $\sim$10 and the addition of about 30 cm^3 free hydrogen per liter. They found that much of the oxygen formed radiolytically in the core rapidly recombined once out of the active zone, and, in fact, residual gamma activity accelerated this recombination. The excess hydrogen tended to decrease further the remaining oxygen. (Subsequent operating experience with the Hanford carbon-steel loop has shown that simple degasification, such as a pressurizer bleed, may be adequate to maintain oxygen below problem levels.)

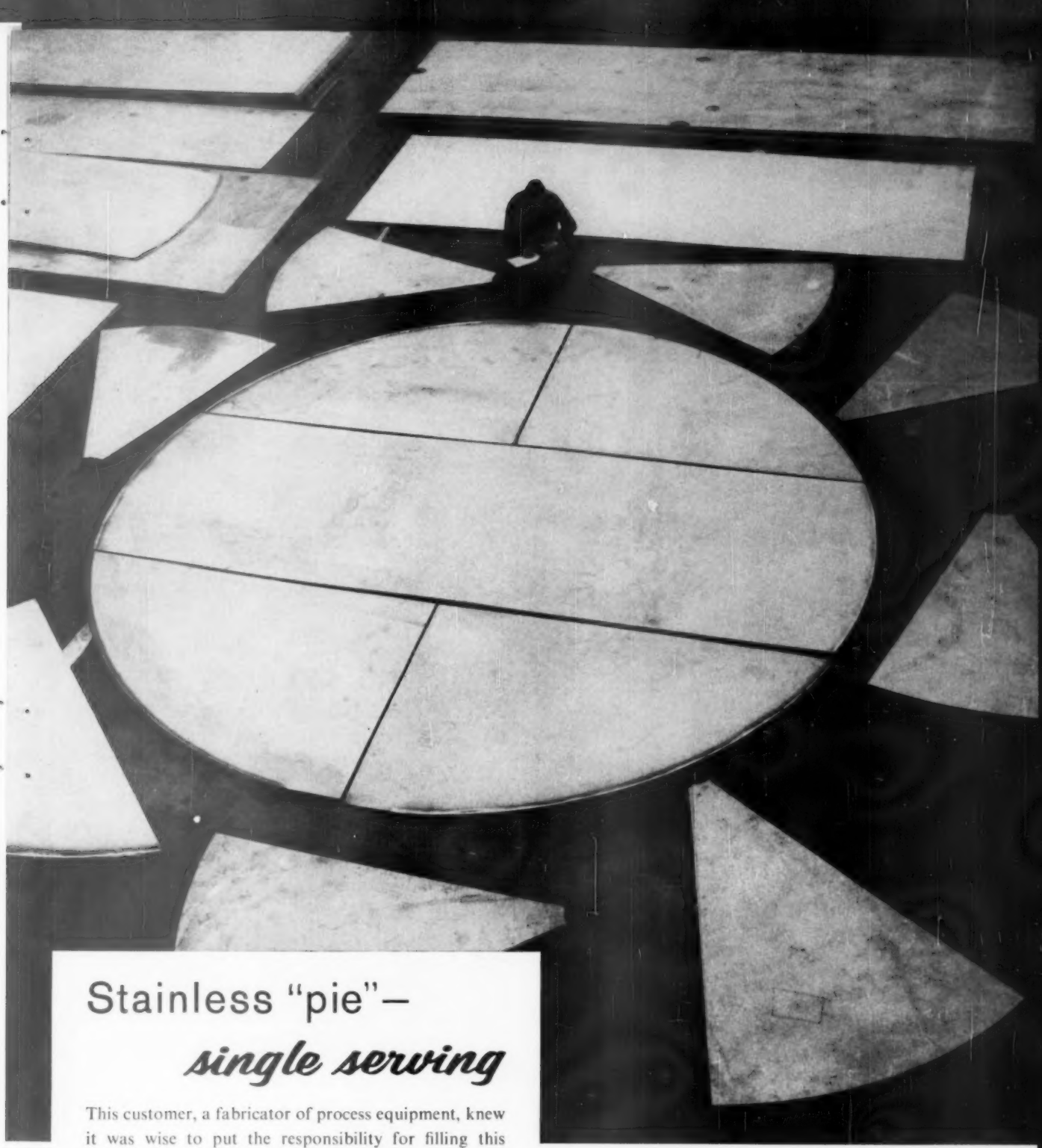
Chemical decontamination. The Navy program also gathered data relating to the activity levels in a loop operated with their recommended water chemistry. Their results were clouded, however, since their test loop (S1W) is actually a carbon-steel heat exchanger in an otherwise stainless-steel loop.

Although the stainless corrosion rate is considerably lower than that of carbon steel, some of the corrosion products produce very long-lived radioisotopes (notably Co^{60}). Data from the Hanford loops indicate the activity level from an all-carbon-steel system may in fact be somewhat lower than that of a stainless-steel system. It appears, however, that it would be economically advisable and in some cases necessary to decontaminate systems of either material.

Radioactive contamination in a nuclear piping system comes primarily from particles that are dissolved or suspended in the coolant as well as deposited in the pipe-wall corrosion film. Ordinarily methods can be devised to prevent this activity level from becoming a serious operational problem; it appears, however, that some maintenance requirements would be extremely costly unless activity can be reduced.

The coolant activity can of course be eliminated before maintenance by draining or flushing, but the deposited activity requires more elaborate procedures. Most of the pipe-wall ac-

(Continued on p. 111)



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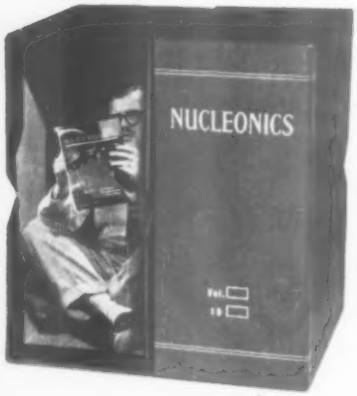

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tivity is removed by chemical dissolution of the corrosion film.

Considerable effort has been expended at Hanford to find suitable decontamination methods. Methods to dissolve the stainless-steel corrosion film are necessarily harsh; however, selectivity (removal of the film with little attack on the base metal) is usually good. The carbon-steel systems are easier to decontaminate although greater care must be taken to prevent excessive base-metal corrosion, but it has been done.

To weigh the merits of the two systems for NPR, an evaluation program was launched in late 1958 based on the data previously mentioned and supplementary studies.

Uniform corrosion. It was concluded that uniform corrosion of carbon steel in optimum water conditions will be about 0.12 mil/yr. The uniform rate is preceded by a more rapid initial rate, but the total initial corrosion is only about 0.03 mil, which is of little importance unless this preliminary corrosion is initiated many times over the life of a system. An undisturbed system would have a total uniform corrosion of 3–5 mils over 25 years.

Nonuniform corrosion. The most serious form of nonuniform corrosion in a carbon-steel system is pitting. It cannot be compensated for by any reasonable corrosion allowance; however, it is prevented in conventional boilers by maintaining very low oxygen levels. (Since stainless steel exhibits serious stress cracking in the presence of oxygen and trace quantities of chloride, either system must be maintained essentially oxygen-free.)

Tests indicated no stress, crevice or caustic corrosion of the carbon-steel system in the optimum water at operating temperatures. There was no evidence of erosion corrosion at velocities below 35 ft/sec.

Decontamination. Decontamination methods that have been developed can reduce the activity of a contaminated pipe wall to an acceptable level with corrosion losses of 0.05–0.2 mil of base metal per cycle.

Since decontamination exposes bare metal, the uniform corrosion of a pipe wall will be boosted by both the decontamination loss and an additional ~0.03-mil initial corrosion. Over 25 yr with monthly decontamination and assuming 0.2-mil uniform loss per cycle, the total corrosion would be about 80 mils. For less frequent cycles, the

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total would drop appreciably.

There is not yet sufficient data to predict exactly the length of this cycle. Preliminary results from the Hanford loops indicate some portions could get by for several months. To be on the safe side, 125 mils is being allowed for the basic primary loop. Of course, this would be impossible for heat exchanger tubes but smaller allowances (20–30 mils) would probably be reasonable for the decontamination cycle of these units; and, due to higher thermal conductivity, this would still allow heat transfer equivalent to thinner stainless steel tubes. Further data from the loops may show this approach to be feasible, but the exchangers were critical schedule items, and it was necessary to make a decision before these data were available. Even though it meant accepting problems associated with a mixed system, the final decision was to procure the exchangers with stainless-steel tubes and tube-sheet clad in an otherwise carbon-steel unit. This is only 300,000 lb of steel (about 8% of the primary loop) but it meant foregoing savings of $0.75–1.5-million.

Uranium oxide and fission products resulting from a ruptured fuel element present another decontamination problem. Progress appears to be satisfactory in the investigation of methods for dissolution of these contaminants.

Water treatment system. Although the corrosion rate of carbon steel is 10–40 times that of stainless steel, the carbon-steel loop has shown equal or less activity than the stainless loops. Further, there has been little tendency in high-pH systems for the solids to foul heat-transfer surfaces as was once feared. The use of carbon steel in the NPR does not appreciably increase the size of the water-treatment plant since it is determined by startup and abnormal makeup conditions rather than normal operating requirements.

Final NPR Decision

It was finally decided that the cost incentive outweighed any foreseeable operational problems. The direct benefit will be the reduced cost of military plutonium. Also, this appears to be one of the gratifying occasions when advancement in military and civilian applications go hand in hand, for the prototypical operating conditions of the MTR mean the direct application of this technology to power reactors—and the potential for cost savings is significant.

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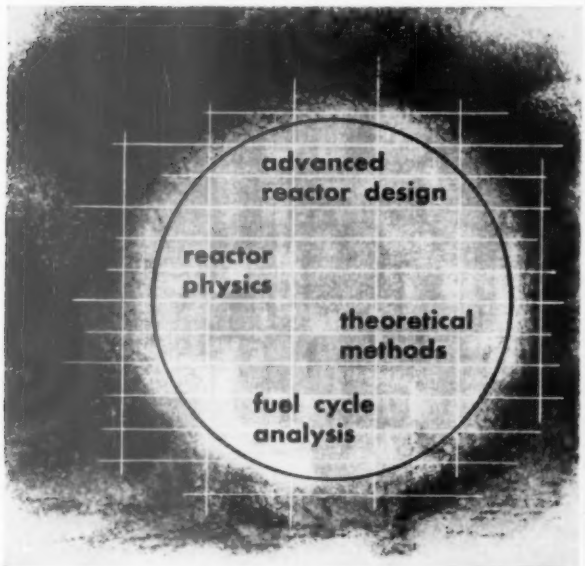

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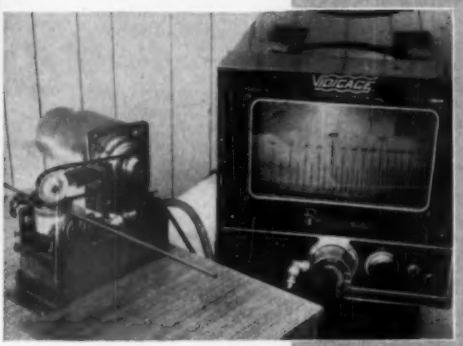

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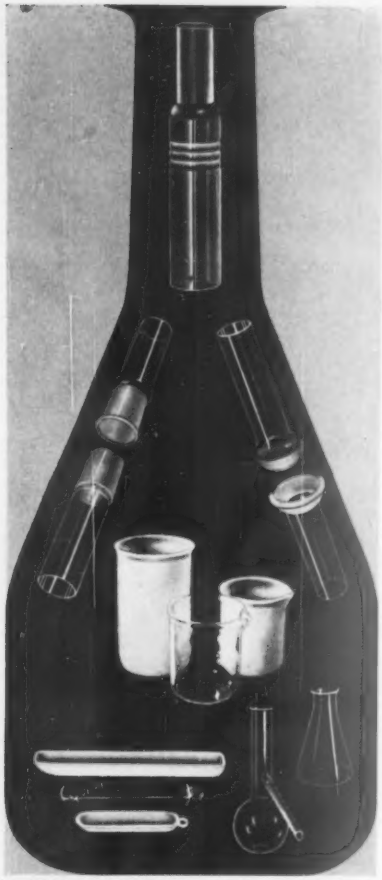

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Neutron Threshold Reactions—An Intercomparison

By C. E. MELLISH, *Isotope Research Div., A. E. R. E., Harwell, England*

A number of fast-neutron reactions, such as $S^{32}(n,p)P^{32}$, occur in fission reactors and can be important in their design and operation. The experimental values assigned to the cross sections for these reactions in the neutron spectrum of a given reactor have been subject to uncertainty for at least three reasons:

- The uncertainty that the fast-neutron spectrum in the reactor used for the cross-section measurement is a true "fission spectrum."
- The uncertainty that measurements made in one reactor will be valid in another; if the fast-neutron spectrum in reactors can, in fact, differ from the fission spectrum, then it is reasonable to suspect that additional differences between different reactors, or different types of reactor, or different irradiation positions in a reactor are present.
- The absence of an agreed, predetermined standard cross section for one threshold reaction, to which other work can be referred. The reaction $S^{32}(n,p)P^{32}$ has been used as a standard and for flux measurements, but different values for its cross section have been assumed—in particular both 30 mb and 60 mb.

The purpose of this article is to show that there is enough evidence in the literature to justify, with a fair degree of confidence, 60 mb for the fission-spectrum cross section of the reaction $S^{32}(n,p)P^{32}$. If this value is taken as the standard, there is more agreement among workers in this field, in different countries and different reactors, than has generally been realized. (Table 1 gives the mean values of cross sections for four other important reactions calculated on this basis.) As a result we can conclude that the uncertainties above are not a source of difficulty in making estimates of the yields of these reactions, or in obtaining results in approximate agreement with those of other workers in different reactors.

Comparison of Results

Table 2 gives some of the published data on threshold-reaction cross sections. The criterion for inclusion in this table is that the reaction concerned has been investigated by more than two authors. Most of the data here were summarized in a paper by Rochlin (*1*); additional work by Roy (*2*), Passell and Heath (*3*) and the author is also given.

Also included in this table are values obtained for four of the reactions by calculation from the known form of the fission spectrum and from the excitation functions of the reactions for monoenergetic neutrons. The mean cross section for fission neutrons $\bar{\sigma}$ is

$$\bar{\sigma} = \frac{\int_0^\infty \sigma(E)N(E)dE}{\int_0^\infty N(E)dE}$$

where $\sigma(E)$ is the cross section of the reaction for neutrons of energy E and $N(E)$ is the number of neutrons in the spectrum with that energy. The calculated figures reported in Table 2 have been derived by the author from the excitation functions obtained by individual workers in the literature (*4–6*) and by Passell and Heath from a compilation of such excitation functions by Howerton (*7*).

Establishing a Standard

The values of $\bar{\sigma}$ gotten from integration of yield curves in the way mentioned above are derived from work by independent workers and are based on neutron fluxes determined accurately under laboratory conditions; moreover,

TABLE 1—Fast-Reactor Cross Sections

Reaction	*Cross-section value (10^{-3} barns)**
$S^{32}(n,p)P^{32}$	60 (assumed)
$Al^{27}(n,\alpha)Na^{24}$	0.56
$Ni^{58}(n,p)Co^{58}$	105
$Fe^{54}(n,p)Mn^{54}$	47
$Fe^{56}(n,p)Fe^{56}$	0.87

* Mean values of published data adjusted to agree with standardized value of $S^{32}(n,p)P^{32}$ reaction; standard deviation of last four values is about 10%.

TABLE 2—Published Fast-Neutron-Reaction Cross Sections (10^{-3} barns)

Author	$S^{32}(n,p)P^{32}$	$P^{31}(n,p)Si^{31}$	$Al^{27}(n,\alpha)Na^{24}$	$Ni^{58}(n,p)Co^{58}$	$Fe^{54}(n,p)Mn^{54}$	$Fe^{56}(n,p)Mn^{56}$	*Where measured*	*Reference cross section*
Hughes(*1*)	30	19	0.6				Unpubl. Argonne 1946	$S^{32}(n,p)P^{32}$ = 30 mb (M)†
Mellish(*1*)	(30)‡		0.24*	45	23	0.44	BEPO, Harwell	$S^{32}(n,p)P^{32}$ = 30 mb (A)‡
Richmond(*1*)	60	31	0.6				BEPO, Harwell	Fast fission of U^{235} = 304 mb (M)†
Robinson(*1*)	(30)‡			225			Oak Ridge	$S^{32}(n,p)P^{32}$ = 30 mb (A)†
Rochlin(*1*)			(0.6)‡	140	56		Brookhaven facility N-5	$Al^{27}(n,\alpha)Na^{24}$ = 0.6 mb (A)‡
Roy(*2*)	(30)‡		0.29*	51		0.49	NRX	$S^{32}(n,p)P^{32}$ = 30 mb (A)‡
Saeland(*1*)	21	(19)‡	0.44				Kjeller reactor, center	$P^{31}(n,p)Si^{31}$ = 19 mb (A)‡
Schumann and Mewherter(*1*)				40	15		Brookhaven 'normal pile flux'	See text
Passell and Heath(*3*)	(65)‡		0.6	91	54	0.82	EBR-1, center	$S^{32}(n,p)P^{32}$ = 65 mb (A)‡
Calculated (Mellish)	61	32	0.5–0.8			0.92		
Calculated (*3*)	65	30	0.59			0.95		

* Previously unreported. † M = measured. ‡ A = assumed.

the four values determined absolutely in this way agree well in relative magnitude with the reactor-determined values. Hence I suggest that the cross section of the $S^{32}(n,p)P^{32}$ reaction be established by convention as 60 mb. This figure cannot be far from the true value. Choice of 60 mb rather than Passell and Heath's value of 65 mb (±5 mb) is indicated only by the fact that it makes no adjustment necessary to the values set by Richmond and Rochlin.

In Table 3 an attempt has been made to reconcile the values of Table 2 on this basis. Where an author has used the S^{32} reaction, his results have been adjusted to give 60 mb as the cross section of this reaction. Rochlin's own results, which were referred to a value of 0.6 mb for the reaction $Al^{27}(n,\alpha)Na^{24}$, have been left unchanged because the results of most of the other authors (adjusted to 60 mb for the S^{32} reaction) do give a figure of about 0.6 mb for the Al^{27} reaction. Schumann and Mewherter's results in Table 2 were based on the assumption that "the fission flux inside a hollow uranium slug is equal to the thermal flux immediately outside it." This has been shown by the author to be equivalent in the Harwell reactor BEPO to assuming a cross section of 22.5 mb for the S^{32} reaction, and so these results have been multiplied by 60/22.5 for insertion into Table 3.

Conclusions

Except for the results of Hughes, Saeland and Robinson, the results for the cross sections of these reactions can be said to agree with each other; the standard deviation of the mean values is ~10% in each case (if the results of the three authors above are omitted). Considering the assumptions made, and the uncertainties, the agreement is remarkably good.

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TABLE 3—Corrected Fast-Reaction Cross Sections (10^{-3} barns)

Author	$S^{32}(n,p)P^{32}$	$P^{31}(n,p)Si^{31}$	$Al^{27}(n,\alpha)Na^{24}$	$Ni^{58}(n,p)Co^{58}$	$Fe^{54}(n,p)Mn^{54}$	$Fe^{56}(n,p)Mn^{56}$
Calculated (P and H)	65	30	0.59			
Calculated (Mellish)	60	32	0.5–0.8			
Mellish	60		0.48	90	46	0.88
Richmond	60	31	0.6			
Rochlin			0.6	140	56	
Roy	60		0.58	102		0.98
Schumann and Mewherter	60			107	40	
Passell and Heath	60		0.55	84		0.76
Values below not included in averages of Table 1.						
Hughes	60	38	1.2			
Robinson	60			450		
Saeland	60	56	1.25			

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Radionuclides in Microspheres

Nuclide	*Half-life*	*Max. specific activity (curies/gm)*
Ba^{140}-La^{140}	12.8d	10^3
Cs^{137}	30y	10
Co^{60}	5.3y	5
Po^{210}	138d	10^3
Sr^{90}	28y	12

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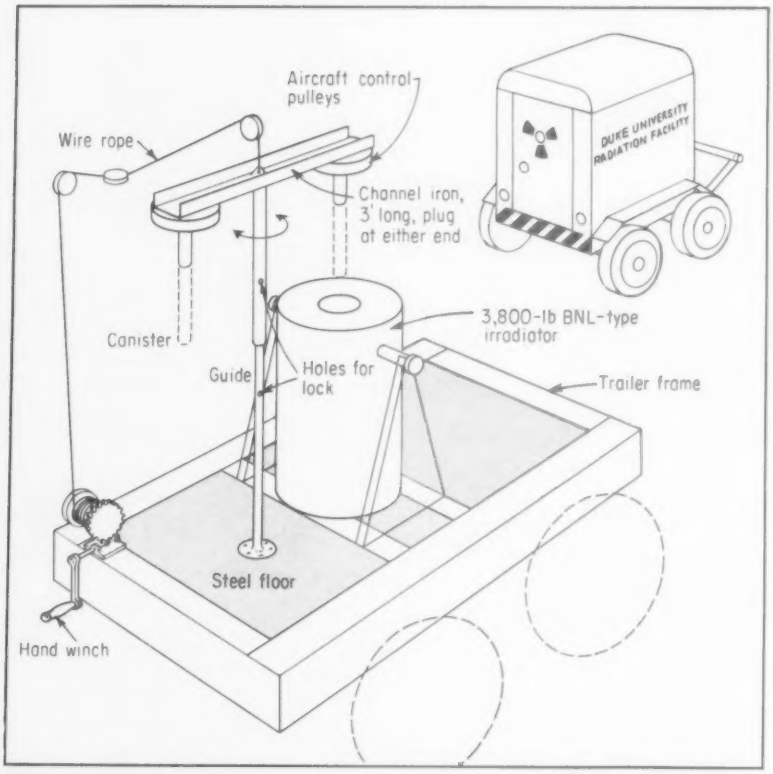

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You can buy the enriched oxygen in water, gas or labeled compounds. The water is also highly enriched in deuterium, but if this is an inconvenience, you can have it reconstituted ("normalized") to the natural abundance of hydrogen isotopes for an additional charge. Prices range from $500 for a gram of water enriched to 3% O^{17} to $300 for 1,000 gm of water that contains 1.5% O^{18}. The institute has a brochure ("Stable Isotopes of Oxygen") for those who need it.

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The paradox that one must wait for permission to use something safer grows out of the fact that tritium, a man-made radionuclide, falls under AEC jurisdiction. Radium, occurring naturally, does not. Since the use of radium developed before the Manhattan Project, it has never been subjected to safety standards as stringent as those applied to radionuclides that are regulated by the AEC.

The new regulation permits not more than 5 mc of tritium per watch hand and not more than 25 mc per face. The man who applies the paint or imports luminous watches must still be licensed. Moreover he must satisfy the AEC that the luminous material has been applied safely and that he has performed some stringent tests with satisfactory results.

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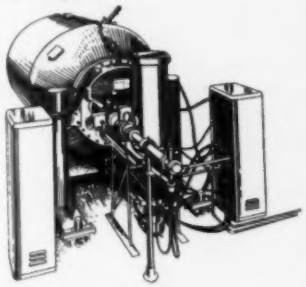

Accelerator Conference

The 2nd Accelerator Conference held recently in Amsterdam was a rewarding occasion for High Voltage and its Dutch affiliate, High Voltage Engineering (Europa) N.V. Three hundred participants from 24 countries joined in this exchange of information on accelerators and experimental techniques. There was some healthy give and take between the "ideal" machine described by the physicists and the "present state of the art" reported by our engineers. If there were no gap between what is wanted and what is commercially available, most of us could pack up and go home.

As things stand, High Voltage continues to push accelerator development to the limit and is glad to share this challenge with its insatiable customers in research.

The Conference Proceedings were published in a January special issue of *Nuclear Instruments and Methods*. Check with your librarian, or write us for a complimentary copy.

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Minor-Constituent Analysis with Neutron Activation

By J. HOSTE, F. BOUTEN and F. ADAMS, *Ghent University, Ghent, Belgium*

Neutron-activation analysis for minor constituents (0.001%–1%) has had relatively little attention as compared with neutron-activation analysis for trace constituents (< 0.001%). With adequate precautions, however, thermal-neutron activation is valuable for elements present at the higher concentrations in complex media. Spiking one of the irradiated samples with an internal standard provides a calibration that takes care of such difficulties as nonuniformity of neutron flux and self-shielding. Such analysis competes favorably with other analyses in accuracy, precision and speed.

In classical analytical procedures elaborate quantitative separations produce unavoidable errors and are time consuming. With activation analysis quantitative separations are unnecessary. In many cases separations can be avoided altogether with adequate counting techniques. Thus the analysis becomes nondestructive.

For minor-constitutent analysis two choices are possible: One can use macroscopic samples with relatively small neutron sources ($\sim 10^7$ n/cm²/sec), which are getting increasing attention as they become available in compact size at moderate cost (*1*). In large neutron fluxes ($\sim 10^{12}$ n/cm²/sec) irradiation time can be reduced if speed is important, or with long irradiations sample size can be reduced to microscopic or ultramicroscopic.

Accuracy

Few data are available about the actual accuracy of trace analysis by activation as no "absolute" standards are available in this field. The accuracy of the results with minor constituents, on the other hand, can be readily checked because analyzed samples are available from different standards institutes.

With due consideration to possible errors from chemical manipulations, interfering nuclear reactions, etc., precision is mainly limited by counting statistics. In determination of minor constituents these will usually be small since concentrations are several orders of magnitude larger than in trace analysis. Thus an accuracy and precision of the same order as with conventional chemical or instrumental methods can be expected.

Inhomogeneity of neutron flux and self-shielding effects can still cause considerable errors, however (*2*). These errors can be avoided, to a large extent with an internal-standard procedure.

Internal Standards

In activation analysis the content of a sample is usually computed from the ratio of the activities of the sample and a known amount of a standard, rather than from disintegration rate, activation cross section and neutron flux.

The difference in neutron flux received by sample and reference can still cause considerable errors, however, which are mainly to be attributed to self-shielding effects if absorption cross sections are substantially different, or to neutron flux irregularities between sample and reference.

To correct for these effects one can use an internal standard (*3*, *4*). Two quantities a and b of the sample are irradiated, an additional amount c of the element X to be determined being homogeneously mixed with b. The material subjected to analysis should contain at least one element Y which can also be activated and measured with good accuracy and independently from the radioactive species due to X. This is possible if, for instance, the half-lives of the activities are sufficiently different that one can analyze the composite decay curve or if the energies of the emitted gamma photons can be resolved with a gamma spectrometer.

Let A and B represent activities in the two irradiated samples. Then the ratio of the activities in the two samples due to Y will be given by

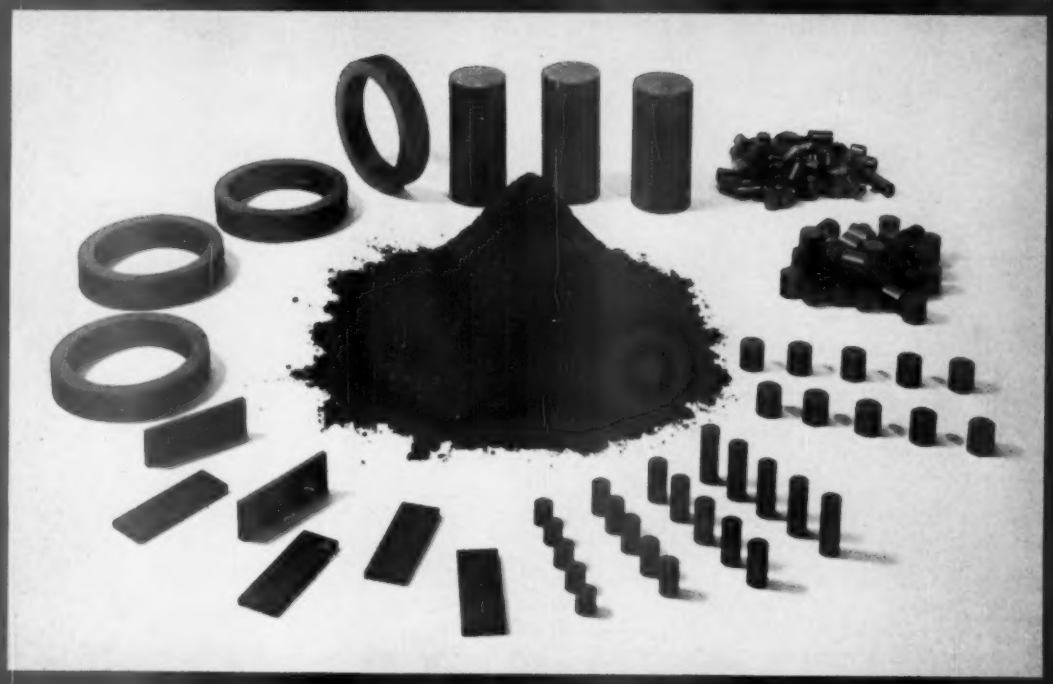
$$\frac{A(Y)}{B(Y)} = \frac{a}{b} \cdot \alpha \qquad (1)$$

(α is a correction factor that compen-

TABLE 1—Steel Constituents Activated by Thermal Neutrons

Element	*Concentration in steel (%)*	*Natural isotope*	*Sensitivity**	*Isotope produced*	*Half-life*	*Radiation and energy (Mev)*
V	2.5	V^{51}	4.5	V^{52}	3.75 m	β^-, 2.7; γ, 1.46
Cu	0.1	Cu^{65}	0.68	Cu^{66}	5.1 m	β^-, 2.63, 1.59; γ, 1.04
Co	up to 45	Co^{59}	17	Co^{60m}	10.5 m	γ, 0.058
Mo	seldom 2	Mo^{100}	0.019	Mo^{101}	14.6 m	β^-, 2.2, 1.2; γ, 0.96, 0.191
Mn	0.25–1.3	Mn^{55}	13	Mn^{56}	2.56 h	β^-, 2.86, 1.05, 0.75; γ, 1.77, 0.82, 2.06
Ni	up to 40	Ni^{64}	0.03	Ni^{65}	2.59 h	β^-, 2.09; γ, 1.49, 1.12
Cu	0.1	Cu^{63}	2.97	Cu^{64}	12.9 h	Electron capture; β^+; β^-; γ, 1.34
As	0.07	As^{75}	4.3	As^{76}	26.4 h	β^-, 0.4–2.98; γ, 0.55, 0.64, 1.2, 1.4, 1.7, 2.05
Mo	seldom 2	Mo^{98}	0.03	Mo^{99}	68 h	β^-, 1.23, 0.45, 0.2; γ, 0.74, 0.18, 0.14, 0.78, 0.367
Cr	up to 20	Cr^{50}	0.73	Cr^{51}	27 d	Electron capture; γ, 0.32
Fe	chief constituent	Fe^{58}	0.0026	Fe^{59}	45 d	β^-, 0.26, 0.46; γ, 1.28, 1.1, 0.19
Ta	1.2	Ta^{181}	21	Ta^{182}	118 d	β^-, 0.53, 1.1; γ, 0.05–1.2
Co	up to 45	Co^{59}	34	Co^{60}	5.2 y	β^-, 0.309, 1.48; γ, 1.17, 1.33

* Sensitivity = product of isotopic abundance and cross section.



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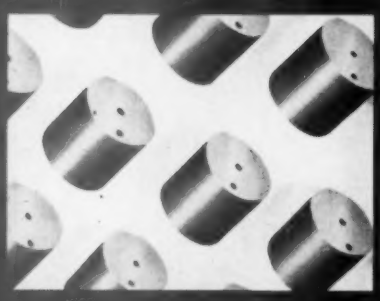

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sates for difference in neutron exposures including any effect of neutron shadowing).

In the unspiked sample (which we are designating by the letters A and a) the specific activity due to X (dps/gm of X) will be given by

$$S(X) = \frac{1}{c}\left[\alpha B(X) - \frac{b}{a}A(X)\right] \quad (2)$$

The percentage of X present in the sample is

$$\%X = \frac{A(X) \times 100}{a \times S(X)} \quad (3)$$

It is clear that simultaneous irradiation of both samples is not needed.

This internal-standard method can be of general use if homogeneous mixing of the element under investigation with the sample is feasible. Errors are still possible, however, if the element to be determined has large resonance peaks in the epithermal region. Self-shielding effects might then differ widely between samples although it will not be apparent from the correction factor α.

Manganese in Steels

Activation analysis with an internal standard has already been reported for

TABLE 2—Activation Analysis of NBS Steel No. 101d

Sample weight (mg)			*Correction factor*	
a	*b*	*c*	α*	% *Mn*
319.36	312.39	5.232	1.071	0.762
320.25			1.486	0.760
282.10			0.928	0.742
305.83			1.193	0.751
319.36	342.81	5.359	1.091	0.777
320.25			1.512	0.775
282.10			0.944	0.757
305.83			1.214	0.766
319.36	317.86	4.877	1.032	0.747
320.25			1.432	0.745
282.10			0.894	0.727
305.83			1.149	0.736
319.36	268.29	5.115	0.618	0.733
320.25			0.857	0.731
282.10			0.535	0.713
305.83			0.688	0.722
			Average:	0.747
			Standard deviation:	2.82%

* See text for definition.

determination of vanadium (*4*) and tungsten (*5*) in high-alloy steels without chemical separation of these elements.

This method has also been applied to determination of manganese in high-alloy steels and cast irons. Manganese occurs as the single species Mn^{55} which gives rise, by an n,γ reaction, to 2.56-hr Mn^{56}.

No chemical separation is necessary since specific measurement of Mn^{56} is possible with a pulse-height analyzer set to count only photons with energies greater than 1.5 Mev. No photons with an energy greater than this are indeed emitted by the other activated steel constituents as is apparent from Table 1.

After complete decay of the Mn^{56}, the correction factor is computed from the integral gamma counting rate of the long-lived species (for example, Fe^{59} and Co^{60}). We made our irradiations in the reflector of BR-1 (site 4) at a neutron flux of $\sim 10^9$ n/cm²/sec. Irradiations in the reactor core can indeed give rise to considerable errors due to an $Fe^{56}(n,p)Mn^{56}$ reaction induced by fast neutrons. This is apparent from the curve of Fig. 1, which shows the Mn^{56}/Fe^{59} activity ratio as a function of cadmium ratio. Interference from a possible $Co^{59}(n,\alpha)Mn^{56}$ reaction appears to be negligible even in the reactor core.

Results on a series analyses of U. S. National Bureau of Standards steel No. 101d (Mn, 0.739%; Cu, 0.184%; Ni, 9.05%; Cr, 18.67%; V, 0.049%; Mo, 0.110%; Co, 0.058%) are in Table 2.

Although all samples were irradiated simultaneously in a standard aluminum can, a considerable variation in the correction factor occurs; it varies from 0.5 to 1.5.

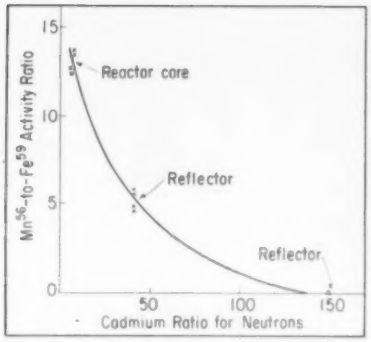

FIG. 1. Fe^{59} COMPETITION with induced Mn^{56} varies with cadmium ratio

Results of analyses of other steel standards are in Table 3, which gives evidence that the method is applicable to widely varying steel types.

It is apparent that the standard deviations in these analyses compare favorably with other instrumental methods of analysis, especially at small concentrations.

As I have already said, the internal-standard technique cannot be applied if the element has large resonance peaks in the epithermal region, because increasing self-shielding occurs for the added element only. This is true with antimony, for instance, as was pointed out by Plumb and Lewis (*2*); an important attenuation of the specific activity of Sb^{122} was observed with increasing sample size; meanwhile the activity of the Sb^{124} isotope remained unaffected. Experiments showed that an antimony

TABLE 3—Magnesium in High Alloy Steels

Sample	*Certified concentration*	*Our measurement*	*No. of analyses*
BCS steel 266 PMA			
Co: 23.4% Ni: 13.3% Al: 7.95% Cu: 3.3% Ti: 0.1% Fe: 49.7%	0.27 ± 0.012*	0.276 ± 0.005	9
BCS steel 233 PMA			
Co: 23.7% Ni: 11.2% Al: 6.98% Cu: 5.09% Fe: 51.15%	0.235 ± 0.005	0.245 ± 0.017	12
NBS No. 155			
Cr: 0.485% W: 0.517% Ni: 0.1%	1.25 ± 0.015 1.24 ± 0.01	1.24 ± 0.050	20
NBS No. 101d			
Cr: 18.68% Ni: 9.05%	0.739 ± 0.004	0.746 ± 0.021	16
BCS cast iron 149			
S: 0.011% P: 0.010%	0.023 ± 0.0018	0.025 ± 0.001	28

* Standard deviation computed from certificates.

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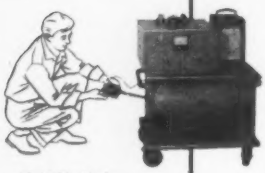

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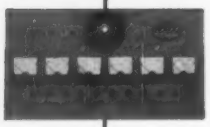

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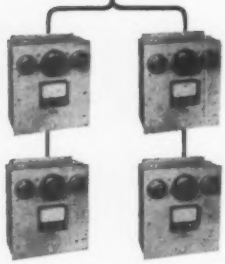

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Activation Analysis

This article starts on page 118

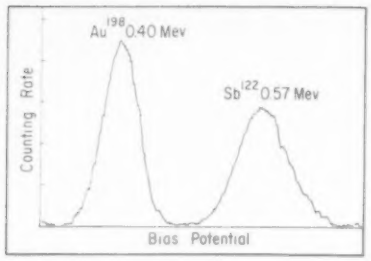

FIG. 2. Sb^{122}, Au^{198} PEAKS are proportional to concentrations in samples

standard (Sb_2O_3) should be mixed with at least 100 times its own weight of very pure graphite to avoid this attenuation. The difficulties due to this resonance effect can be avoided, however, by the use of a standard for which this shielding does not occur.

We therefore spot the lead-antimony alloy with a known amount of gold salt. After activation, the antimony content is computed from the Sb^{122}/Au^{198} activity ratio referred to an empirical calibration curve since other induced activities are negligible.

Gold was chosen as a standard because it meets the following requirements:

- Au^{197} occurs as a single isotope giving rise to only one radioactive species, which has a good yield since the cross section is quite large (95 barns).
- The energies of the gamma radiations (0.40 Mev of Au^{198} and 0.56 Mev of Sb^{122}) are sufficiently different to be measured without interference from each other with a gamma spectrometer, provided that the instrument is compensated for Compton effect. This we did by subtracting the Compton continuum of the NaI(Tl) detector with an anthracene crystal according to the method of Peirson and his colleagues (*7–9*). Peak heights obtained on the spectrogram are then proportional to the counting rates of the respective nuclides. A typical spectrogram is shown in Fig. 2.
- Half-lives of Au^{198} and Sb^{122} are very similar (2.69 and 2.80 days respectively); so that relative counting rates are nearly independent of irradiation period and decay between the end of irradiation and measurement.

To get an accurate calibration curve, we choose such an amount of gold that peak heights for the two gamma rays

are about the same. In view of the cross sections, disintegration schemes and abundances it appears that an antimony-to-gold weight ratio of about 10 is adequate.

Lead alloy disks (diameter 1 cm, thickness 0.05 cm, weight ~0.5 gm) were spotted with ~100 μl of standardized $AuCl_3$ solution (3 mg Au/ml) and evaporated to dryness in the presence of hydrazine. Then the gold-plated samples were wrapped in aluminum foil and irradiated in the core of BR-1 for 1 min at a flux of 10^{12} n/cm²/sec. The gamma spectrum was recorded with a Peirson spectrometer under standardized conditions a few hours after the irradiation. Antimony content is given by

$$\%\text{Sb} = \frac{C(t)}{w} \cdot \frac{h(\text{Sb}^{122})}{h(\text{Au}^{198})} \qquad (4)$$

[$C(t)$ = proportionality constant at time t after irradiation; w = sample size in gm; h's are respective peak heights].

The proportionality constant $C(t)$ is independent of irradiation time provided that the time is short in comparison with the half-lives of Au^{198} and Sb^{122} and is slightly dependent on the decay period since the half-lives are not identical. The value as a function of decay time is

$$C(t)_2 = C(0)e^{-0.693t\left(\frac{1}{2.80}-\frac{1}{2.69}\right)} \qquad (5)$$

As is apparent from Eq. 5 this correction is negligible in the first hours after the irradiation.

In Eq. 4 the activity due to simultaneously formed 60-day Sb^{124} was neglected, as the interference of the 0.60-Mev gamma ray emitted by this isotope, which is not resolved from the 0.56 Mev of Sb^{122} is only 0.3% if measured a few hours after irradiation.

Instrumentation

The arrangement we used for counting our samples is shown in Fig. 3. The instruments used with it are as follows:

- Detectors: Tracerlab RLD-2X and RLD-2 scintillation detectors (3 × 3-in. NaI(Tl) crystal and 1½ × ¼-in. anthracene crystal). Both detectors were coupled to the amplifiers through a White cathode follower.
- Two Nuclear Enterprises Fairstein-type linear amplifiers and single channel analyzers with continuous scanning from a common sliding channel.
- Tracerlab RLI-7 precision high-voltage supply feeding both detectors.
- Differential counting-rate meter.
- Philips XY recorder, type PR 2220 A.

Equalization of the energy scale was by adjusting the gains of the amplifiers, whereas counting rates were regulated by providing an appropriate geometry for the sample between detectors. With this instrument the peak-height linearity as a function of counting rate had a standard deviation of 2.3%.

Three gamma spectra were recorded from each sample. The ratio of peak heights, corrected for decay, are proportional to the antimony content with a standard deviation of 3.4%. As the concentration of antimony can be directly computed from the recorded peak heights, this method can be considered as a first step towards direct reading activation analysis.

* * *

This work is part of the research sponsored by the Institut Interuniversitaire des Sciences Nucléaires.

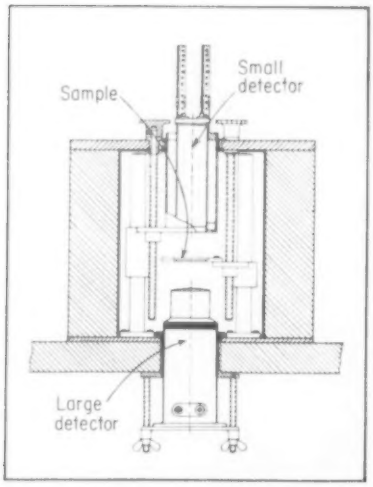

FIG. 3. SIMULTANEOUS COUNTING of standard and specimen uses two detectors

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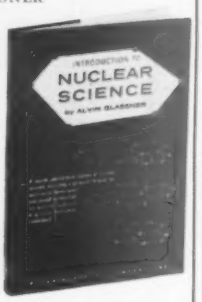

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PRINCETON, NEW JERSEY

Intense Sb-Be Sources Make 10^{10} Neutrons/Sec

By EDWARD J. HENNELLY, *E. I. du Pont de Nemours and Co. Savannah River Laboratory, Aiken, South Carolina*

Intense antimony-beryllium sources give cheap thermal neutrons—as many as 10^{10} n/sec. Although Sb-Be sources with low intensities have been used in the past for cross-section measurements (*1*) and as reactor-startup sources (*2*), only recently has the potential of intense sources been fully realized. These intense sources offer a way of making physics measurements that would normally be restricted to facilities located in and around nuclear reactors or accelerators.

Neutron Source

To make a source we clad antimony with stainless steel and irradiate the antimony in a reactor so that it becomes radioactive (Sb^{124}). When the source is removed, we place it in a housing inserted into a beryllium cylinder. The beryllium emits neutrons from the γ,n reaction. Since Sb^{124} has a half-life of only 60 days, the source should be reactivated two or three times a year. At the Savannah River Laboratory, 10^{10}-n/sec sources have made isotopes for tracer studies and have proved useful for exponential experiments.

Advantages of Source

Our experience at Savannah River shows the versatility of 10^{10}-n/sec Sb-Be sources. They offer a cheap way of getting neutrons with intensities equivalent to those from many sealed tubes and neutron accelerators (*2*); the intensities are great enough for the source to play an important part in many experiments in which reactors normally are used. In addition, since the source runs continuously, experiments with it do not need the supervision and care that one must give reactor experiments. This fact is particularly significant in making irradiations for reactor physics studies (e.g. to find absolute fission-product yields). The source can also be used for measurements at neutron energies between fission and thermal since the source is nearly monoenergetic at 25 kev.

In D_2O the neutron flux 1 ft from a 10^{10}-n/sec source is $\sim 5 \times 10^6$ n/cm^2/sec. At this point the cadmium ratio of gold pins (0.060 in. in diameter) is 150. In H_2O the cadmium ratio is nearly the same at ~6 in. from the source, and the flux is somewhat larger. Thus since the energy of the emitted neutrons is small (25 kev), a large thermal-neutron flux occurs near the source. This flux is qualitatively and quantitatively similar to that in the thermal columns of many research reactors.

When separated from the beryllium, the antimony in our source provides intense gamma radiation (10^4 r/hr at 1 ft) with a mean gamma energy of 1.05 Mev. This gamma intensity is useful for experiments—especially since the cask in which the source is stored can be moved from place to place.

Comparison of Four Radioactive Neutron Sources

Source	*Activity*	*Intensity (10^6 n/sec)*	*Half-life*	*Cost (10^3)*
Po-Be	90 c Po	2	138.4 d	9*
Pu-Be	250 gm†	0.2	24,300 y	1.5‡
Ra-Be	20 gm Ra	2	1,620 y	2‡
Sb-Be	1,000 c Sb^{124}	100	60 d	<5§

* Unit cost. However, source must be replaced once a year.
† Atomic ratio: 1 atom of Pu to 13 of Be.
‡ Fabrication and handling costs only; cost of Pu and Ra not included.
§ Annual cost.

Safety

Despite the potential radiation hazard from intense neutrons and gammas, with safeguards and under proper supervision the sources can be handled safely. By separating the beryllium from the antimony except when neutrons are actually needed, one reduces shielding problems. Under these conditions a lead-filled cask with lead walls ~10-in. thick provides the shielding needed for transportation and storage. During experiments neutron shielding requirements depend on the particular experiments and are similar to requirements for small zero-power reactors.

Cost

A capital investment of ~$3,500 covers the cost of the lead-filled cask ($3,000) and the beryllium ($500). Cost of the irradiation facilities varies with the type of experiment. However, by using simple remote handling devices and keeping personnel out of working areas during experiments, costs can be kept to a minimum. One can establish the cost of irradiated antimony by comparing it with the cost for irradiated cobalt ($2–5 per curie). Assuming a price of $5 per curie for Co^{60}, the cost of maintaining a 1,000-curie antimony source is less than $5,000 per year excluding transportation of the one-ton shipping cask.

Other Sources

Neutron intensities from other more conventional radioactive sources are considerably less than 10^{10} n/sec (see table). If one tries to get 10^{10} n/sec from these sources by using multiples of common sources, the cost is many times as great as the cost of an equivalent Sb-Be source; in most cases this price is impractical.

Shielding represents an additional expense for the antimony source. Although shielding problems are somewhat simpler with the other sources and half-lives are longer, the smaller source strength and the higher-energy neutrons from conventional sources are undesirable in many applications.

* * *

This work was developed under contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

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3. Neutrons from accelerators, NUCLEONICS **18,** No. 12, 64 (1960)

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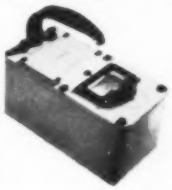

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NUCLEAR BOOKSHELF

The six reviews that follow are of monographs in a series published under the auspices of Nuclear Engineering and Simmons-Boardman Publishing Corp.

NUCLEAR REACTOR STABILITY,

by A. Hitchcock (Simmons-Boardman Publishing Corp., New York, 1960, x + 60 pages, $2.75)

Reviewed by Mortimer A. Schultz, Westinghouse Testing Reactor, Westinghouse Electric Corp., Pittsburgh, Pennsylvania

With the flood of technical literature currently being unleashed there is a groping effort toward literary forms that conserve space and the reader's effort. Hitchcock's "Nuclear Reactor Stability" is one of a series of engineering monographs that appears to achieve this goal. The monograph reviews and condenses what might be a book in the stability field. As set up it does not offer handbook information that is directly usable by the reader, but rather outlines the methods of approach to general and specific reactor-stability problems and gives examples.

The intent of the monograph, according to the publisher's preface, is to give broad coverage of the subject for university students, research assistants, and engineers who normally do not work in the nuclear field. This seems to be the publisher's intent rather than the author's, since the monograph is at a highly technical level and requires considerably more than a casual knowledge of the physics and thermodynamics of reactors. The point of view, as would be expected from Dr. Hitchcock's UKAEA background, is British with most of the examples taken from the gas-cooled, graphite-moderated reactor field.

Stability is defined by first subjecting a power reactor operating in a steady state to an input disturbance. If after a brief transient response the reactor returns to a steady state similar to the original one, the system is said to be stable. If after the disturbance the reactor moves continuously away from the original steady state possibly ending up in some form of shutdown, the reactor is said to be unstable. The input disturbance can be of almost any form; however, the disturbance must be translatable into a change in reactivity.

The stability of dynamic systems in general are then examined using the reactor as an example. The author develops the small signal-disturbance response equations of the physical reactor subsystems. The roots of the characteristic equation formed are then examined for negative real parts to see if the system is stable. Relationships are available between roots and coefficients of the original characteristic equation to determine stability conditions.

This treatment is first presented for lumped average-reactor conditions. It is then expanded to handle spatial variances by noting that the general solution of a problem can be built up from simple solutions with a time response of the form $e^{\omega t}$. When substituted into the original differential equation this solution produces partial differential equations in space only. These equations will only have solutions for certain values of ω; the equation giving these values is the characteristic equation. Approximations are usually used because exact solutions of the equations are inconvenient and not always possible. One method is modal analysis; another is the Q method.

Once he has developed the general mathematical picture, the author presents individual chapters on using this method for problems of temperature instability, xenon instability, void instability, and instability introduced by an external control system.

This monograph offers physicists engaged in the design of large power reactors a method of making stability calculations. The physical-mathematical approach, however, is not particularly suitable for engineers seeking a quick shortcut method of determining stability. I can best describe the situation by an analogy to Ohm's Law in electricity. Ohm's Law is derived from Maxwell's wave equation; for applications such as plasma physics $E = IR$ is too naive. However, for 99.9% of all electrical calculations this simple formula works well. Similarly in the reactor field the servo-engineering methods of analysis work beautifully for conventional reactors. J. Nelson Grace and his group at Bettis have even used the servo technique for the more complicated spatial-stability problems.

Consequently, I feel that the people who use approaches like Hitchcock's are doing it for exercise. There are simpler ways.

NUCLEAR RADIATION MEASUREMENT,

by J. Sharpe (Simmons-Boardman Publishing Corp., New York, 1960, vii + 71 pages, $2.75)

Reviewed by Louis Costrell, National Bureau of Standards, Washington, D. C.

This monograph gives a brief description of the interaction of radiation with matter and a discussion of the more common types of detectors. A few pages are devoted to pertinent electronic instruments. This discussion is followed by a chapter on detection of heavy particles, beta particles, gamma rays and X-rays. Obviously it is not possible to cover the material thoroughly in 71 pages. However, the book should prove helpful to those who meet the somewhat contradictory requirements of being new to the field and yet having sufficient background so that the concessions to brevity are not disturbing.

NUCLEAR REACTOR MATERIALS,

by B. R. T. Frost and M. B. Waldron (Simmons-Boardman Publishing Corp., New York, 1959, vii + 79 pages, $2.75)

This monograph, based on information in lectures by members of Harwell's metallurgy division, is well and tightly presented.

The compact lead-off chapter is an outstandingly fine explanation of the fundamentals of metallurgy. The second chapter covers the essentials of properties and processing of reactor structural metals. This chapter is followed by a too-brief (5 pages) treatment of the highlights of the metallurgy of uranium, plutonium and thorium. The final three chapters deal with ceramics and cermets, liquid metals, and gaseous and aqueous corrosion.

Because of its brevity and use of initials and abbreviations, this book is not completely suitable for the man new to the nuclear field. But it could serve well as a supplementary reading text or outline for a lecture course in reactor materials. From the standpoint of the reactor physicist seeking to learn materials capability, the book tends to emphasize materials processing more than fabricability and properties. Still, this background gives a good foundation on which to proceed into a deeper study of materials. Regrettably, it gives very little coverage to control materials and no real attention to inspection capabilities or radiation effects. —JD

NUCLEAR REACTOR CONTROL AND INSTRUMENTATION, by J. H. Bowen and E. F. O. Masters (Simmons-Boardman Publishing Corp., New York, 1958, 68 pages, $2.75)

Reviewed by John MacPhee, Reactor Development Section, American Machine and Foundry Co., Atomics, Greenwich, Connecticut

The authors have done a commendable job of presenting principles of reactor-plant control in a concise way. Using the Calder Hall reactor as a basis, the author introduces the text with a chapter on rudiments of reactor power plants. This discussion is followed by chapters on neutron kinetics, reactor thermal response, control rods and drives, and instrumentation.

Although it is written in a practical vein, the book is more than just a superficial treatment of the subject. For example, in obtaining the transient axial distribution of temperature in a coolant channel, the validity of separating time and space variables is discussed along with the conditions under which such an approximation can be made. Also in the chapter on neutron kinetics some useful approximate methods are mentioned for obtaining reactor response to various types of reactivity forcing. Another chapter discusses working examples.

The text is well written and in general is quite lucid. If fault must be found, it is in the omission of examples involving other reactor types and the fact that the frequency-response method is not discussed. Aside from these minor complaints, this monograph more than satisfies its objective of serving as an introduction to engineers concerned with reactor design.

STEAM CYCLES FOR NUCLEAR POWER PLANT, by W. R. Wootton (Simmons-Boardman Publishing Corp., New York, 1958, 66 pages, $2.75)

Reviewed by John MacPhee, Reactor Development Section, American Machine and Foundry Co., Atomics, Greenwich, Connecticut

The objective of this monograph is to explain in an elementary way the considerations involved in selecting steam cycles for nuclear power plants.

Approximately one-third of the text is devoted to steam cycles for gas-cooled reactors. The single-pressure, dual-pressure and reheating steam cycle are discussed with emphasis on the effect of reactor-coolant conditions in selecting steam-cycle parameters.

Brief discussions of water-moderated reactors and liquid-metal-cooled reactors are also given.

The latter half of the book consists of appendicies on heat-balance calculations, steam-turbine design, and the Mollier and temperature-entropy diagrams; the book also gives working examples of steam cycles and a derivation of the relationship between reactor gas-outlet temperature and the attainable over-all thermal-cycle efficiency.

The author has written an excellent text for those people unfamiliar with steam cycle design. However, because so much space is taken up with fundamentals, the book offers little to the experienced engineer.

NUCLEAR REACTOR SHIELDING, by J. R. Harrison (Simmons-Boardman Publishing Corp., New York, 1958, 68 pages, $2.75)

Reviewed by Paul E. Thurlow, Reactor Development Section, American Machine and Foundry Co., Atomics, Greenwich, Connecticut

This short monograph cannot be realistically described as a shield design handbook. Since it is impossible to contain the hodgepodge of shielding cookbook lore in 68 pages. Nevertheless, the author has done a remarkable job of lucidly explaining the principles and basic formulas of shield design, providing a logical basis for further inquiry by the uninitiated reader. Although abbreviated in its discussions, the text is filled with useful quantitative data; discussions include accompanying equations and numerical values of parameters.

As a reference work, the book is especially valuable in giving references to most of the important detailed works on shielding theory. This is a real boon to the beginner or absent-minded expert, since the sources of useful shielding information are diverse and often obscure. For this purpose, and as an introductory shielding text, the book is highly recommended.

Books Received

Annual Review of Nuclear Science, Vol. 9, edited by E. Segrè, G. Friedlander and W. E. Meyerhof (Annual Reviews, Inc., Palo Alto, Calif., 1960, 617 pages, $7.00). Reviews in this volume are Neutrino Interactions (Reines); Nuclear Interactions of Heavy Ions (Zucker); Cosmic Ray Showers (Greisen); Bubble Chambers (Bradner); Optics of High-Energy Beams (Chamberlain); Nuclear Structure Effects in Internal Conversion (Church, Weneser); Recoil Techniques in Nuclear Reactions and Fission Studies (Harvey); Labeling of Organic Compounds by Recoil Methods (Wolf); Nucleon-Nucleon Scattering Experiments and Their Phenomenological Analysis (Stapp, MacGregor, Morovcsik); Theoretical Interpretation of the Energy Levels of Light Nuclei (Talmi, Unna), Appendix (Ajzenberg-Selove, Lauritsen); Nuclear Method for Subsurface Prospecting (Beckerley); Experiments on Cosmic Rays and Related Subjects During the IGY (Ney); Cellular Radiobiology (Alper); Vertebrate Radiobiology: Metabolism of Internal Emitters (Thompson); Late Effects (Storer, Grahn).

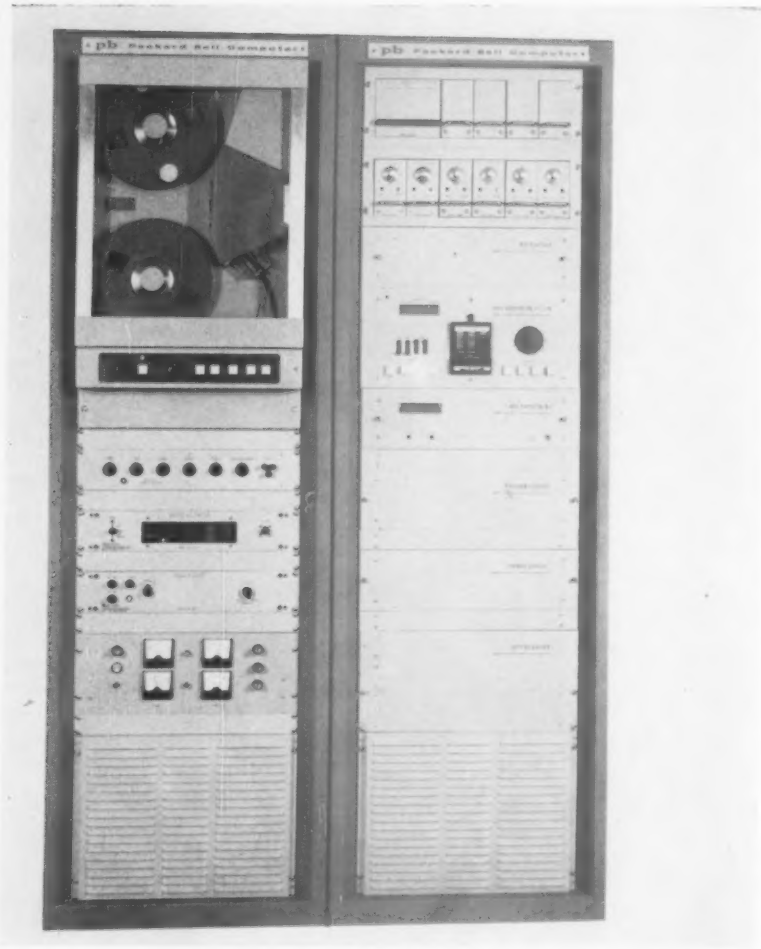
Progress in Nuclear Physics, Vol. 8, edited by O. R. Frisch (Pergamon Press, New York, 1960, 304 pages, $15.00). Topics covered include: cosmic rays and the origin of the elements; polarized nucleons; collective motion in nuclei; Cherenkov detectors; dispersion relations for elementary particles; and pion production by photons.

Progress in Nuclear Energy, Series IV, Technology, Engineering and Safety, Vol. 2, edited by R. Hurst, R. N. Lyon and C. M. Nicholls (Pergamon Press, New York, 1960, 799 pages, $15.00). This volume contains edited papers selected from those presented at the Second Geneva Conference in the field of reactor technology (additional papers on reactors are in Series II). The papers are listed under five topic headings: Reactor Chemistry; Reactor Materials; Engineering Experience and Practice; Engineering Studies; and Engineering Aspects of Reactor Safety.

Also of Note

Engineering and Technical Conventions 1961 offers a comprehensive, advance listing of engineering and technical meetings and conferences to be held in the United States during 1961; it provides dates and locations of almost 700 state, regional and national meetings on technical subjects ranging from acoustics to high-polymer physics to welding. 42 pages, $4. *Industrial Relations News, 230 W. 41st St., New York 36, N. Y.*

Energy and the United Nations contains key UN studies on different aspects of the field of energy. Besides a report on atomic energy, the pamphlet discusses fossil fuels, electric and wind power, solar energy and the economics of energy development. Edited by A. G. Meczerik, 66 pages, $2.50. *International Review Service, 15 Washington Place, New York 3, N. Y.*



Logger with Computer for Reactors

Solid-state digital system, recently delivered to Argonne National Laboratory for reactor monitoring and control, is flexible and expandable because its heart is a PB-250 digital computer. This 250-channel data-logging system, which has 50 channels of off-normal alarm, can grow to keep pace with future needs because the computer's stored program can be changed, thus modifying the system operation in many ways. Besides this flexibility for adaption to future tasks, the system also has great capabilities as a logging system. Calibration, scaling and linearization of transducer signals are made in the computer. Thus many nonlinear transfer functions can be made without analog correction. The system accepts six analog input-voltage signals ranging in frequency from direct current to 40 cycles/sec, amplifies the signals and digitizes the voltages with a sampling rate of at least 2,000 samples/sec. The data is then recorded on magnetic tape in IBM 704 format.—Packard Bell Computer, 1905 Armacost Ave., Los Angeles 25, Calif.

Monitor for Hanford Reactor

High-speed temperature monitor measures temperatures at 120 points on 46 ft cubic production reactor at Hanford. System will later be expanded to monitor 3,600 points. The monitor has a scanning rate of 5,000 inputs/sec, a scan cycle of 0.8 sec and a self-checking feature that prevents false alarms. Solid-state system measures temperatures in volts and converts them to digital form for readout in binary decimal code and isotherm display. Monitor has five kinds of alarm conditions: temperature, rate of change, approach to trip, irrational high or irrational low temperatures. The device, which has 30,000–35,000 components, has operated without a failure or spurious signal for 1,900 hr, 1,250 of which were continuous (20-billion consecutive operations). Thus it has operated faultlessly for >50-million component hours.—Monitor Systems Inc., Fort Washington, Pa.

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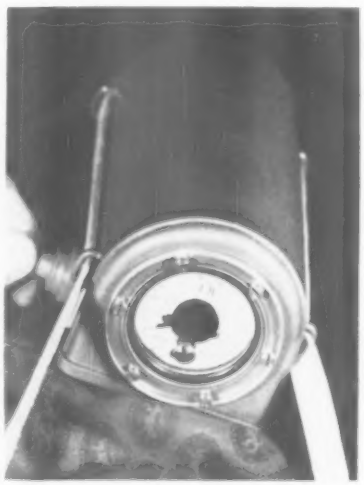

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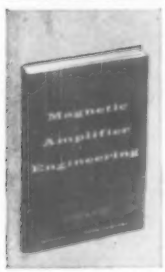

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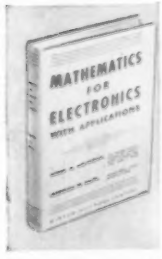

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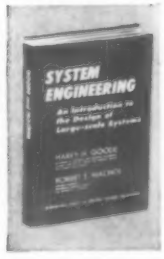

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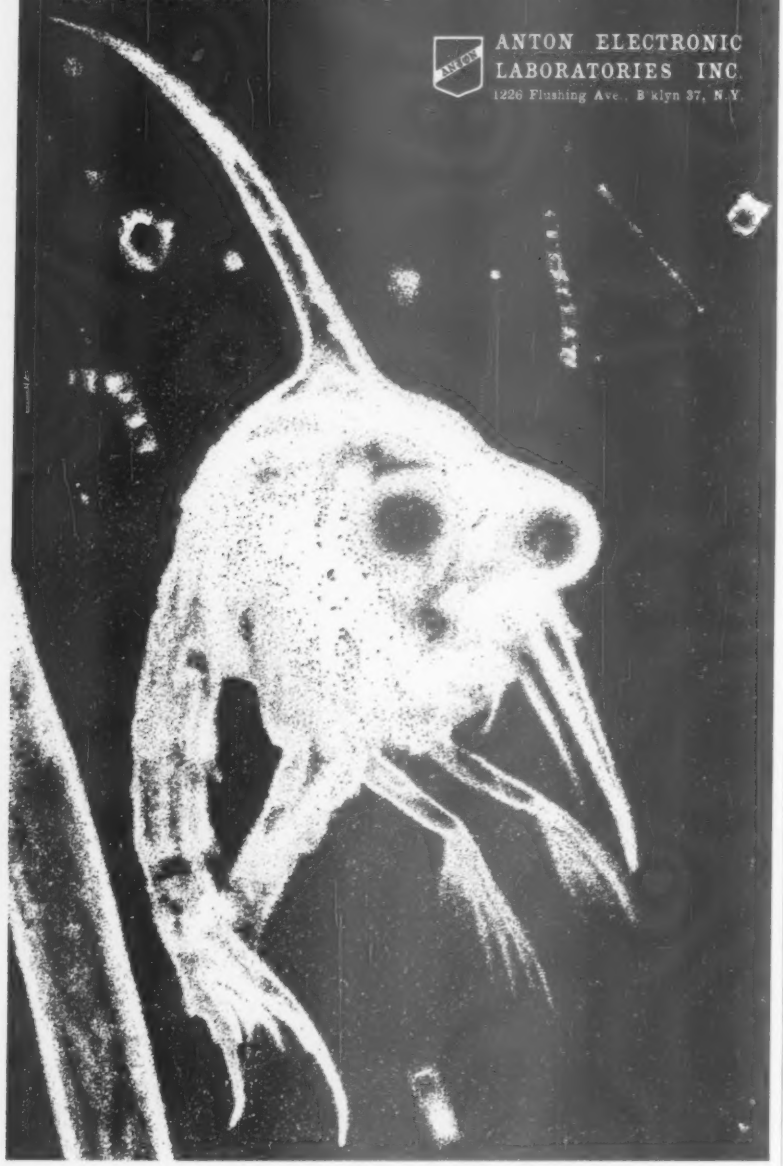

Products and Materials

Department starts on page 128

scale that has an illuminator built in for night use. The meter, which operates for 50 hr on two flashlight batteries, has a stabilized circuit that functions in temperatures from −22° to 125° F with a 15% accuracy.—Gelman Instrument Co., 106 N. Main St., Chelsea, Mich.

Cobalt Irradiator on Casters

MOBILE Co^{60} IRRADIATOR uses 3,000-curie source. Shielding reduces dose rate to <10 mr/hr at surface.—Isotopes Specialties Co., Burbank, Calif.

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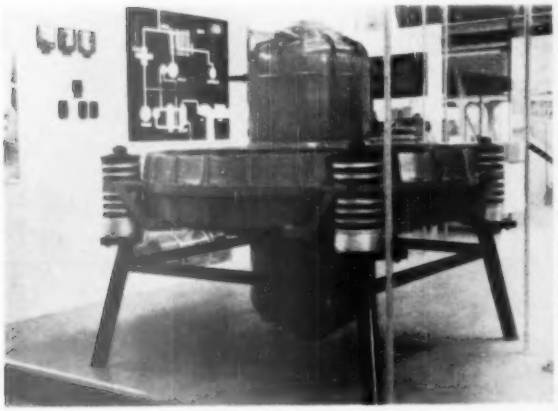
Drives for Control Rods

Four Servotran variable-speed drives will raise and lower control rods in a reactor built by the General Atomic Division of General Dynamics. The drives reverse instantly and hold position for remote operation of control rods. A $\frac{1}{40}$-hp motor lifts a 70-lb load at a rate of 6 ft/min. Adjustable stops on a solenoid control allow different raising and lowering speeds to be set.—Humphrey, Inc., 2805 Canon St., San Diego 6, Calif.

Removing Heat from Spent Fuel Shipment

HEAT EXCHANGERS have two closed circuits: internal primary circuit, made of Inconel (shown here), removes heat from water-filled container in which fuel elements are submerged. External secondary circuit, made of copper-nickel alloy, removes heat from primary circuit and dissipates it in air.—American-Standard Ind. Div., Detroit 32, Mich.



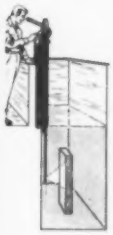
Flywheel Powers Reactor Plants if Mains Fail

GYROAGGREGAT SUPPLIES 8 kwh—enough energy to operate plant auxiliary services. Gyro has 1.5-ton flywheel. Two rotors are coupled to flywheel: one acts as motor, is connected to 50-cycle power-mains supply and drives flywheel at 3,000 rpm; other, a three-phase generator, is self-excited by condensers and supplies three-phase current.—Oerlikon Engineering Co., Zurich, Switzerland.

(Continued on page 132)

LENOX REMOTE VIEWING 'SCOPES FOR NUCLEAR APPLICATIONS

Lenox leads the way in the development of borescopes and periscopes for the inspection of reactor components and other radioactive parts. Both instruments are supplied with offset optics and integral shielding. Of watertight construction and corrosion-resistant materials, they are manufactured in lengths and diameters to fit the application. Adapters for T.V. and photography available.



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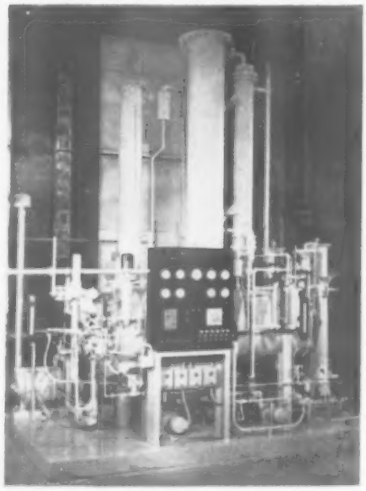
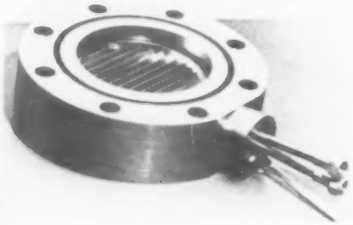
Products and Materials

Department starts on page 128

Chalk River's CO_2 Generator



GENERATOR WILL SUPPLY CO_2 as an inert nonabsorbing purge gas for Chalk River 200-Mw NRU reactor.—Louis DeMarkus Corp., 3080 Main St., Buffalo, N. Y.



Thermoelectric Vacuum Baffle

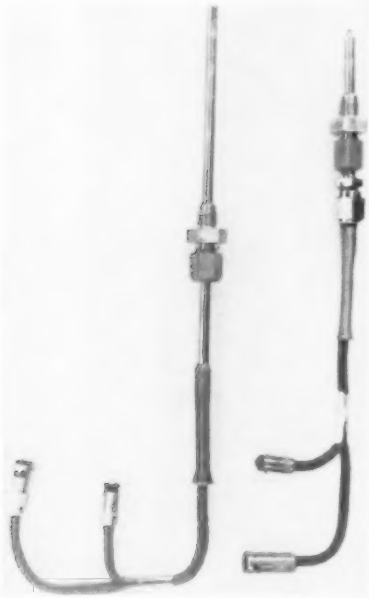
Thermoelectric baffle (above) to be used with vacuum systems is a completely solid-state device that eliminates the need for conventional, mechanical refrigeration equipment. Instead the baffle employs standard semiconductor cooling elements called Frigistors. Baffle, which comes with 2–32-in. diameters, is noiseless, has small power consumption and does not need major maintenance.—General Thermoelectric Corp., Princeton, N. J.

Static Metal Seal

35 K-Seal Atomic, machined from high-temperature stainless steel, will be used in a still-classified, experimental reactor project. The 35-in. seal makes a gas-tight connection at 700° F under 2,000 psi.—Harrison Manufacturing Co., 2908 N. Naomi St., Burbank, Calif.

Scaler for X-Ray Diffraction

N-276 high-speed-printing scaler can be used for X-ray-diffraction counting systems. The scaler features 15 preset counts from 10 to 500,000 counts and operates in preset time and manual modes. Scaler has a pulse-pair resolution better than 1 μsec, repetition rate of 1 Mc, a display of 6 electronic decades and a sensitivity of ±4 volts peak minimum.—Hamner Electronics Inc., P. O. Box 531, Princeton, N. J.

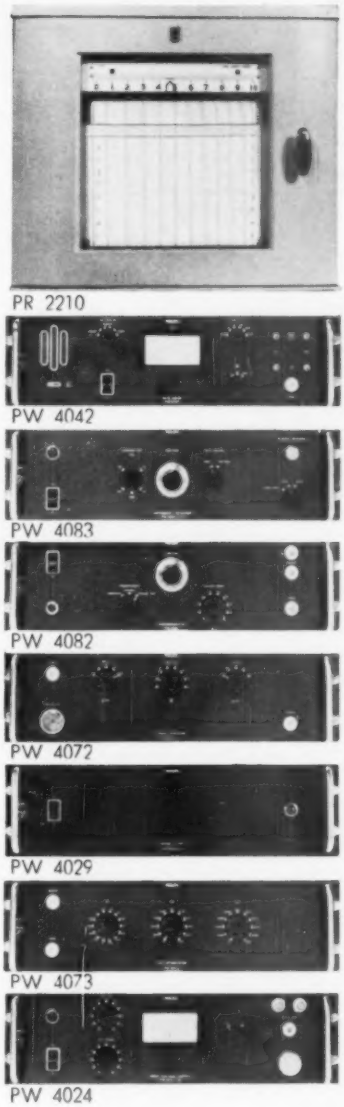


Fast-Response Thermocouple

400 Series, fast-response thermocouples (above) come in exposed or totally enclosed junction configurations. Enclosed-junction type has a 65-msec response time; exposed junction type has 5–10 msec response. Both thermocouples have stainless-steel sheaths and bayonet connectors. Instruments have calibrations of chromel-alumel, iron-constantan or copper-constantan that cover a temperature range of −300° to 2,800° F. Thermocouples work well at pressures of 6,000 psi.—Press-Temp Products, 1120 El Segundo Blvd., El Segundo, Calif.

Pulse Amplifier for Reactors

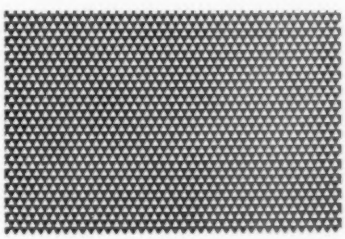
This pulse amplifier can be placed in a reactor control room and connected by only one cable (up to 2,000 ft) to the proportional counter inside the reactor core. The amplifier consists of a low-noise input stage, a step attenuator, a buffer and a high-gain stage. Specifications for the instrument include: in-



Automatic Single-Channel Gamma Spectrometer

for the qualitative analysis of radiation patterns produced by separate radio-active isotopes or by isotope mixtures. The instrument is also used for quantitative measurements of radiation, for the determination of the purity of isotopes, to study scattering and absorption effects.
The instrument is equipped to produce differential as well as integral spectra.
Both manual and automatic operation provided. Four scanning times; chart speed adjustable to obtain uniform curve length.

HALF-VALUE WIDTH guaranteed better than 9½% (for the 662 KeV photopeak of Cs 137) with scintillation detector PW 4119 and preamplifier PW 4071 - **HIGH VOLTAGE RANGE** 300-2500 V in steps of 22 V - **REGULATION AND DRIFT** H.V. variations less than 0.005% per 1% mains fluctuation. Drift less than 0.05% in 24 hours - **LOG. ATTENUATION** 1-660 x, in steps of $10^{0.002}$ - **AMPLIFIER RESOLUTION** 1 μsec (5 μsec for 100 x overload) - **CHANNEL HEIGHT** 4-100 V (10-turn helical potentiometer) - **CHANNEL WIDTH** 1-2-4-8-12-16-20-24-28-32 V - **SCANNING TIMES** 3.5-14-24-100 min - **MEASURING RANGES** 300-1000-3000-10 000-30 000 c.p.m. - **TIME CONSTANT** 0.1-1-3-10-30-100 sec.



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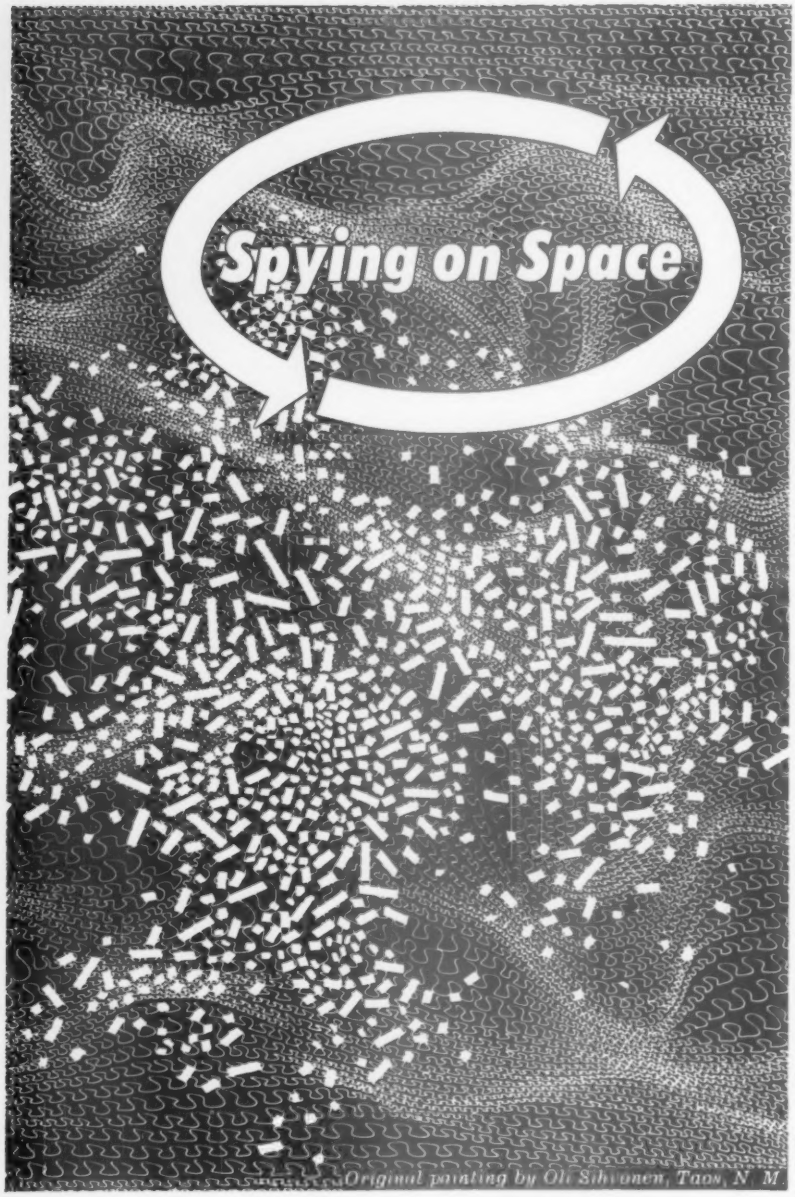

Original painting by Oli Sihvonen, Taos, N. M.

Through the use of tissue equivalent dose rate meters carried on various high altitude research rockets, Los Alamos scientists are learning much about radiation in space, including its possible effect on humans. The instruments simulate human tissue, observe the effects of radiation and telemeter the data back to earth.

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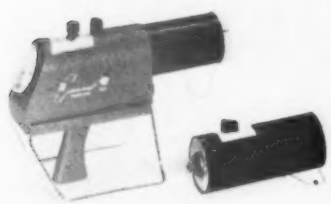
put voltage sensitivity, minimum of 0.2 mv; current gain, 800; apparent voltage gain, 20,000; output voltage, 2 volts with 600 volts applied to proportional counter measuring neutrons from Pu-Be source; rise time, 0.1 μsec; pulse width, <1 μsec; noise level, 0.3 volts peak to peak.—General Electric Co., 1 River Rd., Schenectady, N. Y.

Plant for Water Purification

A mobile plant purifies water from biological, chemical and radioactive contamination. First part of process removes biological and chemical impurities; second part removes radioactive contamination. Each part is contained in a truck (above); a collapsible liquid reservoir holds 350 gallons of water. Second part consists of two ion-exchange columns and a dosing unit. A "mixing-bed" ion-exchange resin consisting of 35% acid-cation-exchanger and 65% alkaline-anion-exchanger is used. The anion exchanger is colored to show when the resin is exhausted. Of the two ion-exchange columns, only one is an operating unit; the other is a safety unit with a G-M tube for continuous monitoring.—Krupps, Essen, West Germany.



Gun-Type Survey Meter

Integrating-rate survey meter, Model 2586-S (above), provides both rate of dose and accumulated dose measurements. The instrument monitors beta, gamma and X-radiation of low and medium intensity; it also measures

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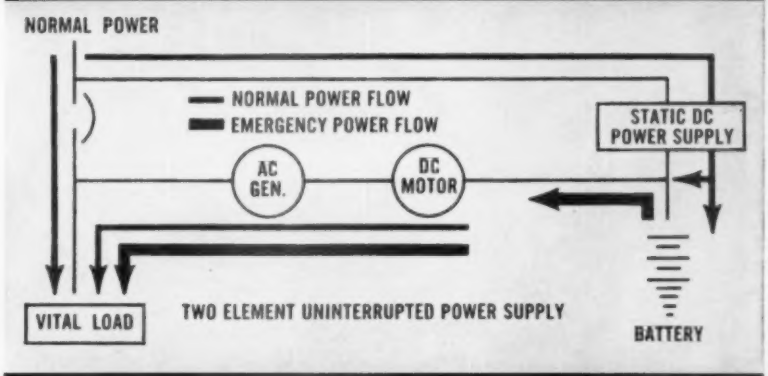

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In one representative system arrangement, an AC generator is driven by a DC motor which derives power from a regulated rectifier in parallel with a long-life storage battery. When power fails or varies the rectifier, which normally supplies power to the DC driving motor, is disconnected and the battery provides surge-free power to the motor—*in zero time*. When prime power is restored, the system automatically reverts to standard operating conditions and the battery is restored to readiness by the main battery charger.

Also available in 2 and 3 unit systems operating in parallel with or isolated from the line, Kearfott's compact uninterrupted power systems also provide audible and/or visual alarms to indicate over- and under-voltage, overload or ground conditions.

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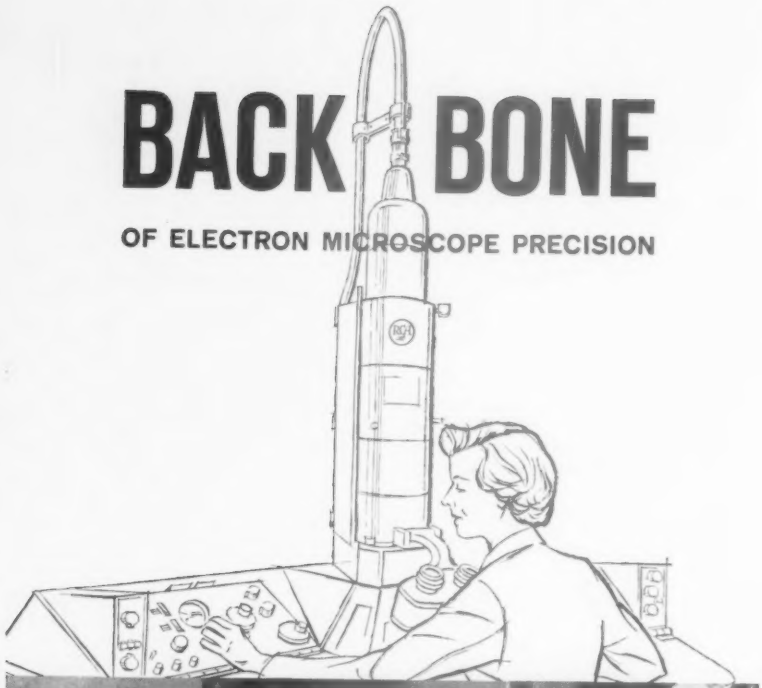

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alphas with energies as small as 4.5 Mev. Survey meter has two interchangeable ion chambers for two modes of operation: rate chamber gives measurements in 0–25, 0–250 and 0–2,500 mr/hr; integrating chamber gives accumulated measurements in ranges 0–0.25, 0–2.5, 0–25, 0–250 and 0–2,500 mr. Energy dependence in both chambers is ±4%.—Nuclear Chicago Corp., 359 E. Howard Ave., Des Plaines, Ill.

Camera for Oscilloscope

C-12 camera (above) that accepts Polaroid or any conventional film gives undistorted viewing and direct recording of oscilloscope traces. Camera has a sliding back on which one can interchange par-focal, film-holding backs. Eight interchangeable lenses with varying object-to-image ratios and maximum aperture of f/1.5 are available with the camera.—Tektronix, Inc., P. O. Box 500, Beaverton, Oregon.

Mobile Air Monitor

AM-28, which was designed principally to protect personnel working near reactors, detects radiation in air-borne iodine vapors. It detects, measures and records the amount of specific gamma activity in energy range of 0.33–0.55 Mev. When a preset alarm level is reached, a bell and light both signal a warning.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Self-Testing Flux Amplifier

Flux amplifier with wide range and freedom from drift provides reactor power-level data for visual display, recording or logging, control, shutdown or scram operations. The amplifier, which is adjusted by an internal, fixed

resistor over a 10^{-7}–10^{-3} amp range, is self-tested by a pulse generator that puts 100-μsec pulse of scram-level amplitude through the amplifier once each second. The instrument has a zero drift of $<0.5\%$, a response time <5 msec and a solid-state power supply that furnished 1,400 volts.—General Electric, Schenectady 5, N. Y.

Fast Neutron Detector

RSN-48 (above) is a fast neutron, proton-recoil, Hurst-Type proportional counter manufactured to Oak Ridge National Laboratory specifications. Since the relationship between neutron absorption in the polyethylene liner and that in human tissue is known, the detector is valuable in radiobiology, radiation protection, neutron shielding and neutron physics. It measures tissue doses within $\pm 5\%$, over a neutron-energy range 0.5–14 Mev. Detector has a built-in alpha source (Pu-239) for calibrating electronic equipment at any time without need for external sources of radiation. This source is positioned by an externally operated solenoid.—Reuter-Stokes Electronic Components, Inc., Cleveland 14, Ohio.

Nuclear Gages

Micro + Meter provides thickness, density and level measurements as well as flaw detection. Since it records individual interactions with radiation, the gage has large sensitivities and small statistical fluctuations. A low output impedance provides response speeds in the millisecond range. Drift

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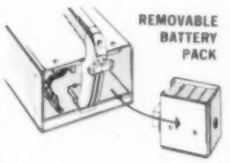
NEW MODEL JUNO SURVEY METER

MODEL 7

The Juno Survey Meter is a portable instrument which measures the intensity of, and discriminates between alpha, beta, and gamma radiation. The Model 7 is the newest version of the original Hanford instrument. It features a hermetically sealed switch box and desiccant cartridge. These design improvements insure high efficiency performance under adverse humidity conditions. Additional features include a high impedance circuit, a large open-face meter, and a new improved battery pack with considerably longer life.

Another STEP FORWARD BY T/A!



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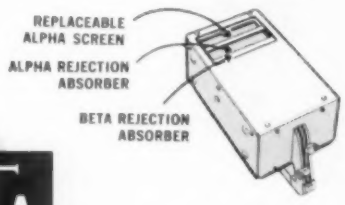

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Products and Materials

Department starts on page 128

is <1 part in 1,000 per day in output signal. In gaging, the following sensitivities result for steel: for range 0–10 in. using Co^{60}, sensitivity is 0.0012 in.; for 0–0.003 in. using Kr^{85}, sensitivity is 0.000002 in.—Radionics Inc., Lafayette and Water St., Norristown, Pa.

Analyzer Table and Cabinet

Mobile Model 73-1 offers space for detector and experimental set-up along with analyzer and typewriter on top and rack space for tape punch, parallel-to-serial converter and amplifiers in space beneath table top.—Radiation Instrument Development Laboratory, Inc., 61 E. North Ave., Northlake, Ill.

8 New Activation Foils

Circular activation foils made from indium, silver, gold and cadmium come in 1-in. and ½-in. diameter sizes. Thicknesses range from 0.005 to 0.02 in. One-in. diameter foils are used in suberitical assemblies, neutron howitzers and low-level pulsed neutron devices. Half-inch diameter foils are used in reactors, particle accelerators and high-level pulsed neutron sources. —Reactor Experiments, Inc., 1485 Bayshore Blvd., San Francisco, Calif.

LITERATURE AVAILABLE

Nuclear Accessory Catalog. 6 pp.; Servonuclear Corp., 28-21 Astoria Blvd., Long Island City 2, N. Y.

Capabilities and Products Catalog. 79 pp.; AECL, P. O. Box 93, Ottawa Ontario, Canada

Manual of Nuclear Medical Instruments. 22 pp.; Curtis Nuclear Corp., 1645 W. 135th St., Gardena, Calif.

Instrument and Filter Catalog. 43 pp.; Gelman Instrument Co., 106 N. Main St., Chelsea, Mich.

Emergency Power Units. 7 pp.; Consolidated Electric Corp., 880 Canal St., Stamford, Conn.

Ultrasonic Cleaning Equipment Catalog. 28 pp.; National Ultrasonic Corp., 111 Montgomery Ave., Irvington 11, N. J.

Radioactive Decontamination Reference Chart. 5 pp.; Turco Products Inc., P. O. Box 1055, Wilmington, Calif.

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New Advances in Radiation Detection. 4 pp.; Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Gammacell 100 and Gammacell 200. 4 pp.; AECL, P. O. Box 93, Ottawa, Canada

Liquid Scintillation Counting Systems. 4 pp.; Tracerlab Inc., 1601 Trapelo Rd., Waltham, Mass.

Radiation Detection Instruments. Radiation Instrument Development Lab. Inc., 61 E. North Ave., Northlake, Ill.

Bendix Dosimeters and Chargers. 2 pp.; Atomic Accessories Inc., 811 W. Merrick Rd., Valley Stream, N. Y.

Hand and Foot Monitor. 3 pp.; Eberline Instrument Corp., P. O. Box 279, Sante Fe, New Mexico

Transistorized Survey Meters. 2 pp.; Servonuclear Corp., 28-21 Astoria Blvd., Long Island City 2, N. Y.

Continuous Radioactive Gas & Liquid Analyzers. 2 pp.; Atomic Accessories Inc., 811 W. Merrick Rd., Valley Stream, N. Y.

Electronik Recorders & Indicators. 48 pp.; Minneapolis-Honeywell Regulator Co., Wayne & Windrim Aves., Philadelphia 44, Pa.

Dual-Channel Potentiometer Recorder. 4 pp.; Varian Associates, 611 Hansen Way, Palo Alto, Calif.

Gamma Spectrometer System. 11 pp.; Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

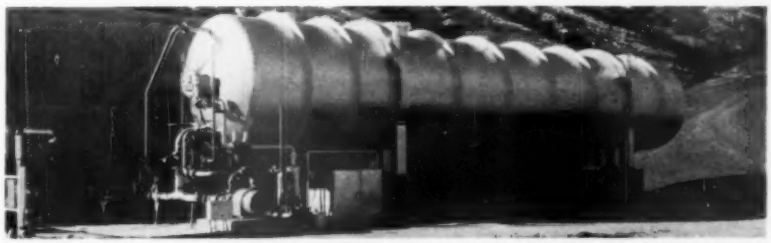
Services in All Fields of Computer Application. 7 pp.; **Nuclear Engineers and Consultants to the Free World.** 7 pp.; Internuclear Co., N. Brentwood Blvd., Clayton 5, Missouri

15 Mc Oscilloscope. 4 pp.; Hewlett-Packard Co., 275 Page Mill Rd., Palo Alto, Calif.

RCL Analyzers. 2 pp.; Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

Van de Graaff Neutron Source. 4 pp.; High Voltage Engineering Corp., Burlington, Mass.

Readout Lamps. 4 pp.; Westinghouse Lamp Division, Bloomfield, N. J.



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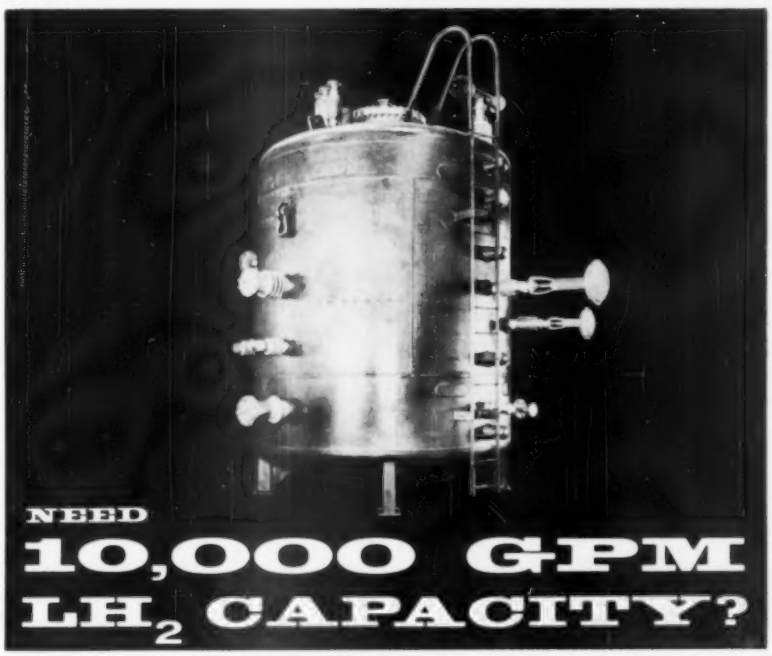

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INDUSTRY NOTES

● **Spencer Chemical Co.,** Kansas, has been awarded a contract by **General Electric Co.** to supply about 40,000 lb of ceramic-grade uranium dioxide to be used for fabrication of fuel for the Humboldt Bay reactor near Eureka, Calif.

● **The Advanced Systems Development div.,** of Pneumodynamics Corp., El Segundo, Calif., has been contracted by AEC to test the integrity of containers to be used for low-level radioactive waste disposal at sea. Containers will be submerged to 1,000 fathoms (6,000 feet) in an area in the Santa Cruz Basin—32 miles from Port Hueneme, Calif.—and will be photographed to determine structural behavior of the various types to be tested. **Edgerton, Germeshausen and Grier, Inc.,** Santa Barbara, Calif., under a subcontract, will provide photographic and radiological health services.

● A complex 350-ton remote-servicing system for the Experimental Gas-Cooled Reactor (EGCR) being constructed at Oak Ridge, will be built under a $2.1-million subcontract by **McKiernan-Terry Corp.,** Harrison, N. J. **Allis-Chalmers Mfg. Co.** designed the machine.

COMPANY ACTIVITIES. New facilities in Waltham, Mass., have been acquired by **Baird-Atomic, Inc.,** Cambridge, Mass., to handle its expanding defense-contract activities . . . **Saint Gobain,** France, has grouped its nuclear work under a new subsidiary, **Saint Gobain Nucleare,** with a $5-million capitalization . . . **CERCA** (Compagnie pour l'Etude et la Realisation de Combustible Atomiques) has plans to operate, by early 1962, a fuel-fabrication plant near Grenoble for natural-uranium elements . . . **Sintercast** div., of **Chromally Corp.** has moved from its Yonkers, N. Y. plant to 43,000 sq-ft facilities at 171 W. Stern Highway, West Nyack, N. Y. . . . **Malinckrodt Chemical Works,** St. Louis, has plans to reorganize along divisional lines now that a two-year study and planning program are completed. Three new divisions will be created: Industrial, Medicinal and Nuclear. The nuclear div. will be headed by Charles D. Harrington . . . **General Electric Co.,** seeking to develop better fuels and materials for nuclear power plants, has expanded and centralized its Atomic Power Equipment dept.'s chemical and metallurgical laboratory under a $100,000 program. This expansion and laboratory facility is in addition to GE's new $1.3-million Chemistry and Metallurgy Laboratory at Vallecitos which is nearing completion . . . **Loral Electronics Corp.,** and **Radiation Applications Inc.,** both of New York, have established, in a joint venture, **Radiation Materials Inc.** Investigation and development of irradiated insulation products such as polyolefin wire and cable are planned. Loral is a supplier of electronics systems and RAI specializes in chemical materials for the electronics industries as well as conducting research and development in atomic energy, plastics and nuclear physics.

NEW BUSINESS. **Allis-Chalmers Mfg. Co.'s** Atomic Energy div., Milwaukee, has awarded **M&C Nuclear Inc.,** Attleboro, Mass. (a Texas Instrument Inc., subsidiary) a contract to supply fuel elements for the Pathfinder reactor to be built near Sioux Falls, S. Dakota. The first fuel elements are scheduled for shipment in November 1961 . . . **Tracerlab, Inc.,** Waltham, Mass., has received an order from Brazil for medical radioisotope instrumentation for the new medical center at Brasilia . . . **Fansteel Metallurgical Corp.,** N. Chicago, Illinois, has formed a subsidiary, **Fansteel, A.G.** in Switzerland. Fansteel produces and fabricates refractory metals, tantalum, tungsten, columbium and molybdenum, etc. "The foreign subsidiary will place Fansteel in a stronger competitive position in the international markets," a company spokesman said . . . **Edlow Lead Co.,** Columbus, Ohio, under a contract from Westinghouse, will design and build casks for shipment of irradiated fuel for reprocessing from Westinghouse's test reactor at Waltz Mill, Pa.

FINANCE. **Deuterium Corp.,** founded by Jerome S. Spevack who invented a process of extracting deuterium oxide from ordinary water, has completed a public sale of 30,000 shares of its prior preferred convertable stock. The firm has moved from its temporary offices to permanent headquarters at 360 Lexington Ave., N. Y.

NEWSMAKERS

● **Ralph D. Bennett,** manager of General Electric's Vallecitos Atomic Laboratory since it was established in 1956, has retired and returned to his farm in Maryland. He will assume a post as director of research with Martin Co. Before his duties at Vallecitos, Bennett was manager of the technical department at Knolls Atomic Power Laboratory at Schenectady. He left the staff of the Massachusetts Institute of Technology in 1940, and holds the U. S. Legion of Merit, and the Navy Meritorious and Distinguished Civilian Service Award. **W. Kelly Woods** has been appointed acting manager of Vallecitos.

Bennett

● **William C. Burch,** who recently supervised construction of the research reactor at Seibersdorf, Austria, for AMF atomics has been given a leave of absence to join the International Atomic Energy Agency. He will assist the Iranian government in construction of its research reactor, and associated laboratories at the Nuclear Center at the University of Teheran. Burch is the first expert sent out by IAEA to supervise a reactor project for a Member State.

● **Melbourne A. Forrest,** a vice-president of the consulting firm of Burns and Roe, Inc., New York City, has been appointed to the firm's board of directors. He will continue to be responsible for the firm's projects in power, nuclear and industrial fields.

● **John H. Harley** has been named director of the AEC's Health and Safety Laboratory for the New York Operational Office. He succeeds **S. Allan Lough** who has been named assistant director for Radiological Physics in AEC's Biology and Medicine div., Washington. Harley has been with the laboratory since 1949, when he became Chief of the Laboratory's Analytical Branch. In 1959 he was named assistant director of HASL.

Harley

● **Logan B. Emlet** has been appointed vice-president of Union Carbide Nuclear Co., a division of Union Carbide Corp. He has been general manager of production at AEC's Oak Ridge Laboratory, and Paducah gaseous diffusion plant, operated for AEC by Union Carbide.

● **Robert C. Hammersmith,** assistant manager of construction for Kaiser Engineers, has been named the resident manager of the AEC's New Production Reactor project at Hanford, Washington. He succeeds the late **John H. Tacke.** Hammersmith was chief construction engineer for Kaiser during the construction of the plutonium production reactors at Hanford, completed in 1955.

Hammersmith

● **J. Donald McBride** has been appointed the deputy chief of the Plans and Policy Branch, Division of Military Application at AEC's Germantown, Md. Headquarters. He was formerly the deputy director of the Budget and Finance div., at the Savannah River Operation Office.

● **John T. McGraw,** formerly general manager of the Montebello div., of U. S. Industries, Inc., has been named director of engineering for the Yard div. of Royal Industries, Inc., Pasadena, Calif. He will be responsible for the development and manufacturing of precision equipment for nuclear and aerospace industries.

● **Rudolf L. Mössbauer** has been awarded the 1960 Research Corporation Award by the California Institute of Technology and Research Corp., a science foundation. He was cited for his discovery of the gamma-ray-resonance effect that bears his name (NU, Jan. '61, 52).

● **Ralph P. Stein,** formerly director and technical advisor to the AEC-sponsored Heat Transfer Research Facility at Columbia University, has assumed his new post as advisory engineer and manager of the heat transfer section Engineering dept., of Nuclear Development Corp. of America.

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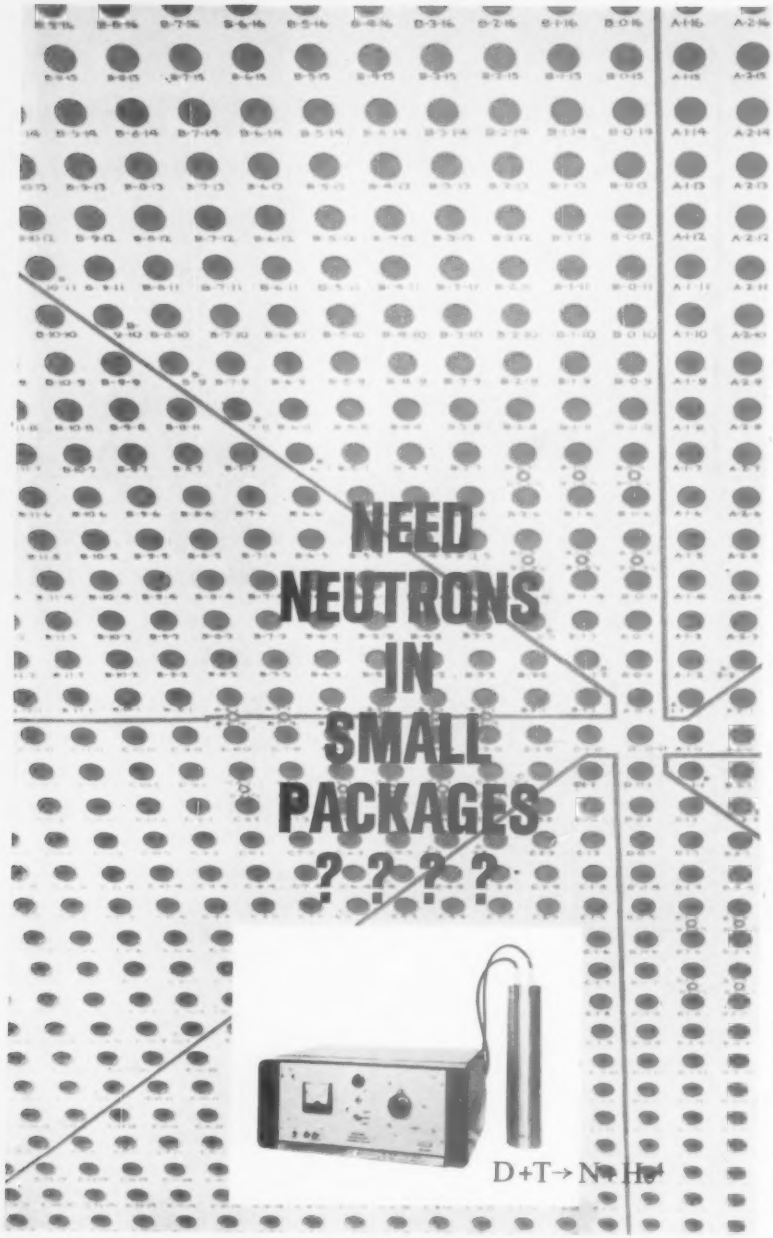

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Newsmakers

Department starts on page 141

● **Walmer E. Strope** has been appointed associate scientific director of the U. S. Naval Radiological Defense Laboratory in San Francisco. He replaces **Eugene P. Cooper** who was appointed scientific director last July. Strope, who joined the laboratory in 1948, is a recipient of the Navy Distinguished Civilian Service Award for his contributions to atomic defense.

Strope

● Allis-Chalmers Mfg. Co. has appointed **John L. Ficken** assistant engineer in the Thermal Power dept., and **Frederick J. Ross** engineering assistant in the Nuclear dept.

● New officers elected to the Council of Cern (European Organization for Nuclear Research) for 1961 are: **Jan Willems** (Belgium), president, succeeding **Francois de Rose** of France; **Edorado Amaldi** (Italy), and **Jan Hendrick Bannier** (Netherlands), vice-presidents; **Cecil Powell** (United Kingdom), chairman of the Scientific Policy Committee; and **W. H. Alexander Hock** (Federal Republic of Germany), chairman of the Finance Committee.

● General Electric Co. appointed **Robert P. Gleason,** safety engineer in health physics and safety at Knolls Atomic Power Laboratory; **Eugene W. O'Rorke,** manager of the newly established irradiations service operations at Vallecitos Atomic Laboratory; **William H. Long,** manager of new applications and contracts section of GE's Aircraft Nuclear Propulsion dept.; **Eugene T. Hubbard,** manager of operations of GE's test reactor at Vallecitos; **W. N. Mobley,** manager of manufacturing, fuel preparations dept., and **Charles M. Salina,** electrical component manager at the Hanford facilities.

● Niagara Mohawk Power Corp. has assigned **Gerald K. Rhodes** to its Nuclear Engineering staff. Rhodes was formerly sales liaison specialist of nuclear systems with the Atomic Energy div. of Babcock & Wilcox Co., New York.

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NUCLEAR CALENDAR

March 9–10—Second Symposium on Engineering Aspects of Magnetohydrodynamics, University of Penna., Philadelphia, Pa. (*University Museum*). Sponsors: AIEE, IAS, and IRE. Contact: Hunter P. McCartney, Publicity Director, Burroughs Corp. Laboratories, Box 872, Paoli, Pa.

March 20–23—Annual International Convention of the Institute of Radio Engineers, New York (*Waldorf-Astoria Hotel and New York Coliseum*). Sponsor: IRE. Contact: E. K. Gannett, IRE, 1 East 79th St., New York 21, N. Y.

March 28–29—Nucleonics in Flight Symposium, American Nuclear Society, Dallas, Texas (*Statler-Hilton Hotel*). Contact: Eldred L. Burkhard, Chairman, No. Texas Section ANS, Convair, Fort Worth, Texas.

April 10–14—First International Conference on Detection and Use of Tritium in the Physical and Biological Sciences, Vienna, Austria. Sponsor: International Atomic Energy Ageney. Contact: IAEA, 11 Kärntner Ring, Vienna 1, Austria.

May 8–10—13th Annual National Aerospace Electronics Conference, Dayton, Ohio (*Biltmore amd Miami Hotels*). Papers are requested. Contact: Ronald G. Stimmel, Chairman of Papers Committee, 1 East 79th St., New York 21, N. Y.

May 11–13—American Radium Society Annual Meeting, Colorado Springs, Colorado (*Broadmoor Hotel*). Sponsor: American Radium Society. Contact: Dr. Charles G. Stetson, Secretary, 350 Engle St., Englewood, N. J.

May 15–17—Radiation Research Society Annual Meeting, Washington, D. C. (*Sheraton-Park*). Sponsor: Radiation Research Society. Contact: E. L. Powers, Secy-Treas., Division of Biological and Medical Research, Argonne National Laboratory, Argonne, Illinois.

May 15–20—Conference on Nuclear Electronics (radiation detectors and monitoring instruments) Belgrade, Yugoslavia. Sponsor: International Atomic Energy Agency. Contact: IAEA, 11 Kärntner Ring, Vienna 1, Austria.

Aug. 28–Sept. 1—Fifth International Conference on Ionization Phenomena in Gases, Munich, Germany. Contact: Sekretariat, Munchen 1, Oskar-von-Miller-Ring 18, Germany.

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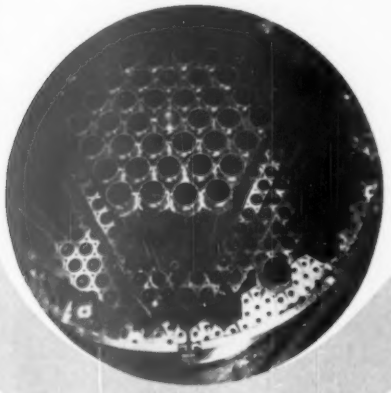

VIEW OF REACTOR CORE, used in HTRE-3 Ground Tests of Direct-Air-Cycle System. Hexagonal fuel tube-moderator bars of hydrided zirconium assembled from center outward. Each tube receives single fuel cartridge. (ACTIVE CORE contains 150 moderator bars.) Small tubes standing alone hold control rods of clad europium. Reflector blocks of beryllium at periphery.

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Today G.E. engineers and scientists, under Government contract, are designing a high-performance Direct-Air-Cycle aircraft nuclear power plant. Concurrently a developmental aircraft is being designed. Both are scheduled for flight in the mid-60's.

Long Range Future for Reactor Systems

Flight testing is just a beginning. Much will be learned after the nuclear powered plane gets into the air. Progress from there on is immeasurable. While the first prototype is scheduled for a high-performance, high-payload, subsonic aircraft, nevertheless – with the technology now in hand – the potential exists to power a supersonic as well as an extremely high-payload subsonic vehicle. Other applications are in the offing: nuclear ramjets and rockets; space auxiliary power; energy for space propulsion (ion and magnetic engines); compact high-performance reactors for a variety of applications.

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EXTRACTS FROM PERFORMANCE DATA RECORDED IN HTRE-3 AT IDAHO TEST STATION

	Predicted	Measured
Max fuel element temp .....(°F)	1,880	1,900
Max moderator temp .....(°F)	1,175	1,120
Max temp discharge air from fuel (°F)	1,640	1,640
Average temp discharge air from fuel ...(°F)	1,430	1,435
Reactor pressure drop .....(psi)	6.05	6.2
Pressure drop, compressor to turbine ....(psi)	10.8	9.3

NOTE: research and development for the Direct-Air-Cycle power plant has yielded many valuable by-products for other nuclear programs including: Pluto, Rover, Snap, Tory II, the Army reactor program and many civilian reactors.

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NEW ADVERTISEMENTS

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Following pioneer achievements in reactor power plant developments, The Knolls Atomic Power Laboratory is now studying major problems in reactor and power plant simplification. Solutions to be achieved may considerably advance nuclear reactor applications.

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Send resume to:

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CHANCE VOUGHT AERONAUTICS DIVISION

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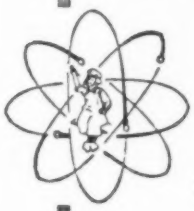

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NUCLEONICS

MARCH, 1961

The SL-1 Accident—on Balance

In the SL-1 accident of January 3 the nuclear industry has suffered its first fatal reactor accident. While it may seem obvious, the very fact that that accident did occur is its first lesson for us.

Indeed it was inevitable that there would be a first fatal accident—it is equally inevitable that there will be more. All of our careful attention in hazards reports to "maximum credible accidents" still leaves open the possibility of some perfectly credible, very obvious accident mechanisms that are neglected in the necessarily finite considerations of such hazards reports. We feel that the initiating cause of the SL-1 accident will prove to be something quite simple—but, along with other conditions of the shut-down reactor, something not explicitly guarded against in the reactor design. We feel equally certain that even when this particular class of barn doors is locked—as it and others that we *know about* should be—there will be other opportunities for accidents. Accidents *will* occur in the nuclear industry as indeed they do in all fields of human endeavor. Our industry must strive, as it has in the past, to make our safety record as good as possible, but no man's thinking should be based on the assumption that there will absolutely be no reactor accidents.

But even as we recognize that reactor accidents will occur we must not let their inevitability distort our thinking about safety. The nuclear field has always been characterized by great concern for safety—almost a supersensitiveness on this score. This has obscured for us the fact that, whether we do it consciously or not, some balance is struck between the amount of cost and inconvenience one is willing to incur and the accident rate one is willing to tolerate. Such a balance is struck in every field of human activity. The outstanding safety record in nuclear operations shows we have set the balance point much farther in the direction of safety than most industries. Now with the SL-1 accident—and recent siting controversies—there's the danger that we may be swayed to move the balance point still further—too far—in the direction of safety. If this were carried to an extreme, the fatal SL-1 accident could be fatal to the nuclear industry.

In a less than completely rational society these balance points are set in part by contests of will and spirit. Now is the time for those of us who believe in nuclear power to show some spirit, to see to it that our great concern for safety and our achievements in safety are recognized by legislators, judges and the public at large.

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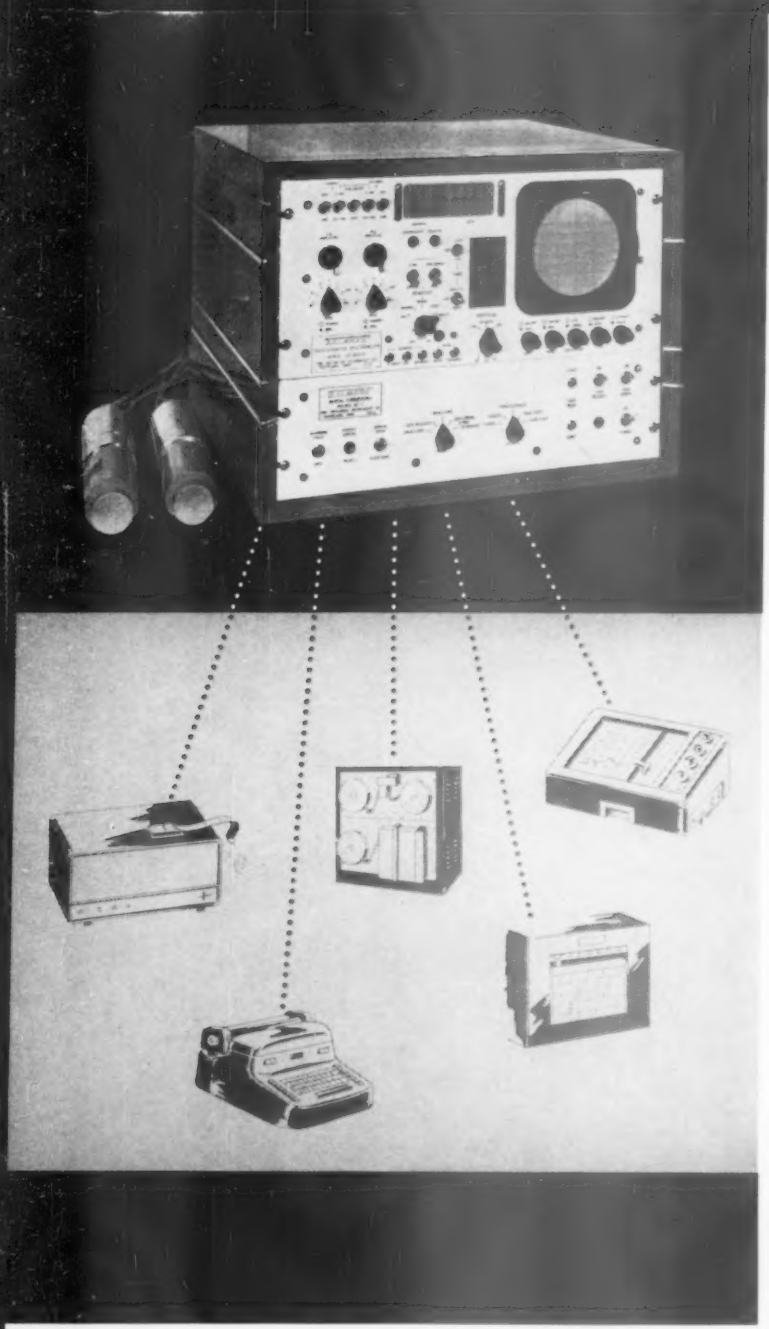

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